MAIZE RESPONSE TO NITROGEN, PHOSPHOROUS, OTHER NUTRIENTS, AND PLANTING DENSITY.

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I. INTRODUCTION.

Two of the basic problems in the tropical world, namely: the increasing need for food and the continually increasing population have emphasized the importance of obtaining the highest food production with the available resources. Despite this need for increased food production, crop yields in the tropics have remained low, a problem which could be alleviated with management and fertilization appropriate for the environmental conditions of the areas where the crop is grown.

Even though maize is a staple food crop in many tropical countries, grain yields in the tropics are still low. While farmers of the temperate region are getting grain yields of up to 10 Mg ha^{-1}, tropical farmers are frequently getting yields of only 1 Mg ha^{-1} and even less.

The mineral nutrition of maize has been extensively studied in temperate areas, but comparatively little studied in the tropics. In Hawaii, more than 20 studies on maize have been published, but most of these have focused on the breeding and selection of adapted varieties and on diseases and other pests of maize.

The most important nutrient for providing high yields in maize production is N, deficiency of which limits production more often than any other factor (de Geus, 1973). Unfortunately, there is limited information on N management for crop production in the tropics (Grove, Ritchey and Naderman, Jr., 1979) even though N is commonly the most limiting nutrient in the tropical world (Sanchez, 1972; Fox et al., 1974; Grove, 1979). The importance of N management will increase as the cost of N fertilizer increases and concern about the adverse environmental effects of poor management of N grows (Olson, 1977; Pratt, 1978; Schepers and Mielke, 1981).

After N, P is the nutrient most often limiting production of maize in the tropics; therefore there is a need for more information on P management in tropical crop production because tropical soils frequently have low P levels and high phosphate sorption capacity.

The main objective of this research is to study the effects of different rates of N and P applications on the growth, nutrient content, and yields of field maize grown on an Oxisol in Hawaii. Apart from the need for more information on N and P management, tropical crop production will benefit greatly from more information on appropriate cultural practices and on the roles of micronutrients in crop production. With this consideration, this experiment had supplementary treatments to provide information on the roles of chicken manure, and planting density, in attaining maximum yield and to determine the effects of Cu, Zn and a blanket treatment composed of K, Cu, Zn, and B, in maize growth and production.

Results of this study should be useful in Hawaii and in other areas in the tropics where similar environmental and soil conditions would allow the transfer of agrotechnology developed in Hawaii.

II. REVIEW OF LITERATURE.

2.1. Soil Colloids, Cations and Anions.

Soil colloids may hold and gradually release cations, such as NH_4, K, Ca, and Mg. As such colloids play an important role in plant nutrition. Colloids normally have a negative charge and, therefore, attract cations including H (Arnon, 1974).

Exchanges of cations occur between cations held by soil colloids and those present in the soil solution. This reversible process is called "ion exchange". The total of all electronegative charges on the colloids represent the cation exchange capacity (CEC) of the soil. The kaolinite colloid has a relatively low exchange capacity (5 - 10 meq/100g). Organic colloids have a higher exchange capacity (200 - 400 meq/100g) (Weber and Elrick, 1969).

The percentage of the total CEC of the soil occupied by basic cations (Ca, Mg, Na, K) determines the degree of base saturation. This degree of base saturation increases with the availability of basic cations to plants, the pH level, and the fertility level of the soil (Arnon, 1974). Generally, the degree of base saturation of uncultivated soil is higher in arid than in humid regions, and higher in soils derived from limestone or basic igneous rocks than in those formed from sandstones or acid igneous rocks (Tisdale and Nelson, 1966).

Experiments with excised roots have shown that cations and anions from neutral salts are not necessarily taken up in equivalent amounts. Cation absorption will predominate when the salt consists of a preferentially absorbed cation such as K^+ and a slowly absorbed anion such as SO_4^{2-}. Conversely, anion absorption will exceed cation absorption when the salt consists of a slowly absorbed cation such as Ca^{2+}, combined with a rapidly absorbed anion such as NO^{3-}(Arnon, 1974).

2.2. Nutrient Elements in Maize Production.

2.2.1. Nitrogen (N).

Nitrogen is taken up in large amounts by maize (Cooke, 1975). However, excessive amounts of N produce spongy and weak tissues, predisposing maize plants to lodging and reducing their resistance to adverse weather conditions and diseases (Jacob and von Uexkill, 1963). Since maize can potentially use all the N available in the soil, the maximum yield when N is not limiting, is governed by other production factors (Barber and Olson, 1968).

The amount of N in the plow layer of cultivated soils usually ranges from 0.002 to 0.4 percent by weight (Black, 1968). It is generally assumed that organic matter contains about 5 percent N (Arnon, 1974). The amounts of organic matter in cropped soils depend on the intensity of cropping (Nye, 1963).

Fertilizer N has become a major cost input in the production of maize (Olson et al., 1976). This has encouraged some workers (Escamilla et al., 1979) to evaluate the effects of different price ratios of N fertilizer <u>to</u> maize on the rates of fertilizer N that maximize net return and rate of return to total investment in maize production per unit of land area. The price of N fertilizer is generally high. However, since N is a major factor influencing crop growth (Khera et al., 1976), it cannot be ignored as an input in maize production. The requirement of fertilizer N for high yields, its generally high price, and the ever-present possibility of large leaching losses of inorganic N makes it essential that fertilizer N be managed as efficiently as possible in the humid tropics (Fox et al., 1974).

Nitrogen effects on soil: Nitrogen fertilization of maize may affect certain soil properties. Blevins et al. (1977) studied the effects of N fertilization on soil properties after five years of continuous maize production on a Typic Paleudalf. With increasing rates of N (up to 336 kg N/ha) they found (1) no effect on soil density, (2) a decrease in exchangeable calcium, (3) an increase in exchangeable aluminum, (4) a lowering of soil pH, (5) an increase in organic carbon and (6) an increase in organic soil N.

Nitrogen effects on yield: Nitrogen has large effects on yield and N content of maize grain (Rabuffetti and Kamprath, 1977; Chalk et al., 1975). Rendig and Broadbent (1979) studied maize on a Typic Xerorthent. With N applications of 180 kg N/ha both grain yields and crude protein content of maize grains were nearly doubled. Treatment effects on yields of amino acids ranged from nil in the case of triptophan to about four-fold greater amounts of leucine in grain from plots receiving 180 kg N/ha. In a study designed to calibrate soil test nitrate for predicting relative yield. Robert et al. (1980) came up with functions showing that a range from 10 to 40 ppm soil nitrate-N was correlated with relative yields ranging from 62 to 98 percent of maximum. This study was carried out on a Xerollic Camborthid. Different functions are expected for other soils but the importance of N in maize nutrition cannot be over-emphasized. In greenhouse pot experiments by Terman et al. (1977), great decreases in growth rates of maize were observed soon after the depletion of applied N. Perry and Olson (1975), on the other hand, reported that increasing N levels for maize resulted in increases of grain N and grain to stover ratios. Maize has a noted propensity for accumulating large amounts of nitrate-N which can be assimilated during periods of restricted N supply. For example, studies by Friedrich et al. (1979) indicate that maize plants can compensate for a restricted N supply during grain filling by utilizing nitrate-N stored in the roots and stem. These studies indicate the importance of improving the efficiency of N fertilizer use.

Nitrogen loss by Ammonia Volitilization: Methods of increasing the efficiency of N fertilizer use include minimizing N loss by ammonia volatilization. Fenn and Kissel (1976) reported that incorporation of ammonium compounds into the soil reduced ammonia losses; increasing depth of ammonium-incorporation resulted in reduced ammonia loss and that losses decreased as the cation exchange capacity of soil increased. They found that the effectiveness of soil depth in reducing ammonia loss was associated with soil water content and that decreasing the soil water increased the effectiveness of soil incorporation for reducing ammonia losses. Experimental results of Fenn et al. (1979) indicated that ammonia volatilization from soils after surface application of urea or inorganic N was reduced by calcium and magnesium nitrates or chlorides. Ryan et al. (1981) confirmed that N loss by ammonia volatilization was significantly related to cation exchange capacity. They also reported that N loss was significantly related to pH and calcium carbonate ($CaCO_3$) but was more closely related to clay-sized $CaCO_3$ than to total $CaCO_3$. Studies by Fenn et al. (1980) showed that addition of calcium (Ca) with urea increased plant recovery of fertilizer N more than predicted from laboratory data. Later, Fenn et al. (1981), reported that soluble Ca was effective in reducing ammonia losses from urea when surface applied to both acid and calcareous soils.

Nitrogen loss by leaching: Nitrogen fertilizer use efficiency for crop production may also be improved by minimizing the amount of N lost by leaching in percolating water (Edwards and Barber, 1976a). Experimental data of Jolley and Pierre (1977) emphasized; (1) the close relationship that exists between efficient N utilization and possible nitrate solution, and (2) the importance of establishing and applying rates of N no greater than required to obtain maximum yields. MacGregor et al. (1974) fertilized two clay loam soils for maize for ten or fifteen growing seasons and found that the average rates of movement of the nitrate front for the 10 and 15 year-periods were 1.7 and 1.9 mm/day, respectively. However Long and Huck (1980) studied nitrate movement under maize and fallow conditions in an ultisol and concluded that maize roots effectively prevented leaching of nitrate.

Schuman et al. (1975) studied nitrate movement and its distribution in the soil profile of differentially fertilized maize watersheds in south-eastern Iowa. Reviewing work published earlier, they referred to studies by Power (1970), Linville and Smith (1971) and Pratt et al. (1972). Linville and Smith (1971) found in Missouri that maize fertilized at up to 134 kg N/ha per year for up to 20 years showed no evidence of nitrate movement below the 244-cm depth. However, a large accumulation of nitrate-N was found below 244 cm when 168kg N/ha per year or more was applied. Pratt et al. (1972) concluded from their studies that if fertilizer N application did not exceed crop needs, no nitrate would be available for leaching. Power (1970) similarly concluded that as long as the fertilizer N rate was less than the rate of total N removed by the harvested crop, it is unlikely that nitrate will leach. Working with soil profiles from two Central Illinois fields, Feigin et al. (1974) found that fertilizer application and crop uptake appeared to exert a larger influence on the total amount of nitrate in the soil profile than did movement of nitrate out of the 150-cm profile by leaching. This was so because rainfall in amounts sufficient to redistribute the nitrate within the profile did not lower the total amount of nitrate in the profile.

The movement of unused fertilizer nitrate-N into shallow underground water strata by way of irrigation return flows has become a concern as irrigation has increased (Onken et al., 1979). Studies carried out by Russelle et al. (1981) indicate that grain yield and N uptake were highest with light frequent irrigation as compared to heavy infrequent irrigation. Onken et al., (1979) studied the effects of furrow, sprinkler, and subirrigation on the movement of fertilizer nitrate-N in a supplementally irrigated area in the presence of maize. They observed that movement out of the surface 30 cm was fastest with sprinkler irrigation and slowest with subirrigation. Watts and Hanks (1978) have proposed a soil-water-nitrogen model for irrigated maize on sandy soils. Such models can be used in evaluating the probable effects of different water and N management practices such as reduced irrigation or delayed N application. Data of Hahne et al. (1977) illustrated the importance of proper irrigation practices in reducing nitrate-N loss through irrigation.

Liegel and Walsh (1976) reported that the use of a slow-release form of N may eliminate some leaching and subsequent loss of nitrate-N. An important source of such slow-release forms of N is urea with a coating of sulfur. Terman and Allen (1974) measured the dissolution rates of various sulfur-coated urea (SCU) products in soil. Dalal (1974) studied three soluble-N sources and three controlled-release-N sources (SCU's) and reported that in general, N uptake, grain yield, and apparent N recovery were increased by added N in this order: SCU-0.9 = SCU-1.1>SCU - 8.9 = Urea > Urea - ammonium phosphate = ammonium sulfate. This trend indicates the superiority of the slow-release N sources over conventional N sources. (SCU's are expressed with regard to their dissolution rates: with SCU-0.9 being the least and SCU-8.9 the most soluble). Liegel and Walsh (1976) discussed specifically the importance of SCU in sandy soils. Their experimental results also indicate the importance of SCU when a lot of irrigation water is involved.

However, when situations are not very conducive to leaching, the beneficial effects of SCU may not be readily discernible. Fox et al. (1974) reported that preplant-applied SCU was no more effective than preplant urea in increasing yields or N recovery. This agrees with the findings of Sander and Moline (1980) who reported little difference between the performance of SCU and urea in terms of grain, forage yields and in N uptake.

Dibb and Welch (1976) have discussed the possibility of decreasing leaching and denitrification losses of applied N by preserving it in the ammonium form. This can be achieved by employing nitrification inhibitors such as N-Serve(2-chloro-6-(trichloromethyl) pyridene). According to Guthrie and Bomke (1980), the effectiveness of certain nitrification inhibitors has been demonstrated in numerous laboratory studies. Results of a study by Warren et al. (1975) suggest that N application rates used for maize production may be decreased with no loss in yield if a nitrification inhibitor is used to minimize losses of applied N. Touchton et al. (1979) reported that N Serve was effective in decreasing nitrification rate of both fall- and spring-applied N.

Despite results of laboratory studies, Guthrie and Bomke (1980) maintained that many field studies failed to show any significant crop response to inhibitor treatments. Field studies by Boswell (1977) indicate that fall- applied N (156 kg/ha rate), with or without the inhibitor was as efficient in maize production as a split application of half in the fall and half as sidedressing, or a preplant application plus sidedressing.

Nitrogen application: The timing of N fertilization of maize is also an important consideration for maximizing the efficiency of applied N. Findings by Perry and Olson (1975) indicate that time of N application does affect maize yields. Studies with maize indicate that postplant sidedress applications of fertilizer N resulted in similar or better yields than N applied at planting (Miller et al., 1975, Bigeriego et al., 1979) or before planting (Fox et al., 1974). In the south east of the U.S. Mainland, N applied in November or December is only 49% as effective as N applied the following Spring (Boswell et al., 1974). Chalk and Keeny (1975) reported on some yield trials that showed little differential response between Fall and Spring applied N (Walsh, 1970: Chalk, Keeney and Walsh 1975), and other studies (Stevenson and Baldwin, 1969: Welch et al., 1971) that showed that Spring applied N gives better response than Fall applied N. Frye (1977) reported that fall-applied N from SCU, sodium nitrate or uncoated urea would be less effective on subsequent Spring and Summer growth than Spring-applied N under similar soil and climate conditions.

Another important consideration in the N fertilization maize is the method of application. Rehm and Wiese (1975) recommended that the application of a portion of the N fertilizer with the irrigation water should be the preferred practice for maize production on sandy soils having no accumulation of fine-textured material below the soil surface. The application of N fertilizers in bands has been tried. Creamer and Fox (1980) reported that band application of both urea and diammonium phosphate inhibits root growth around the band mainly because of ammonia toxicity.

The source of N used should also be considered since different N sources may influence maize growth and yield differently. Soon and Miller (1977) reported that the pH of the maize rhizocylinder solution was lowered by the absorption of ammonium and increased slightly by nitrate absorption. Working with maize on a Typic Paleudult, Frye (1977) observed that SCU was more effective than sodium nitrate or uncoated urea. Terman and Mortvedt (1978) also conducted an N source experiment on a Typic Paleudult. They evaluated N sources at multiple rates of N and phosphorous (P). At the higher rate of applied P, yield response to applied N was in the following order: granular ammonium nitrate >> sulfur coated urea > Oxamide > isobutylidene diurea. At lower rates of applied P, phosphorous was too deficient for satisfactory evaluation of the N sources. Results such as this show that satisfactory evaluation of N sources is possible only at adequate rates of other (i.e., the nontest) nutrients. Organic sources of N can also play an important role in maize nutrition. From the results of a ten year field experiment with maize on a Typic Hapludalf, Ketcheson and Beauchamp (1978) concluded that annual applications of liquid poultry manure, containing N equivalent to 112 kg/ha, precluded a requirement for fertilizer N.

Cations and anions from neutral salts are not necessarily taken up in equivalent amounts. Maize requires large amounts of N and the cation/anion equilibrium is very much dependent on the form in which N is supplied to the plant. Since both nitrate and ammonium are rapidly absorbed, it follows that differences in response of maize to the two N forms are related to their effects on the ionic balance of maize and the growing medium (De Wit et al., 1963)

Efficiency of applied nitrogen: The efficiency of applied N may also be influenced by the type of tillage system employed. Moschler and Martens (1975) studied the response of maize to four rates of N under no-tillage and conventional tillage culture. They found that at the highest rate of N, no tillage culture increased the efficiency of the applied fertilizers. Legg et al. (1979) did similar studies and reported that for all N rates (up to 340 kg N/ha), the uptake and recovery of fertilizer N were substantially higher under no-tillage than under conventional tillage.

Some other factors that may influence the efficiency of N fertilizer use by maize have been reported in the literature. Beauchamp et al. (1976) considered genotypic differences in maize. Their studies indicate that there appears to be some potential for the screening and development of hybrids capable of accumulating a relatively large quantity of N or using N more efficiently through translocation from various plant parts. Kissel and Smith (1978) reported on the effects of soil type. On swelling clay soils, there is low recovery of applied N by Coastal bermudagrass in contrast to recovery from coarse-textured soils. Kissel and Smith (1978) demonstrated that immobilization is the main factor responsible for this low recovery. Recovery of applied N by maize is also expected to be influenced by soil type. Isfan (1979) reporting on the influence of precipitation, concluded that winter precipitation can be used to predict the optimum rate of N fertilizer for maize in the spring. He suggested an alternative equation to be used if the winter precipitation is excessive and the spring continues to be wetter than normal. The R values of these two equations are 0.90 and 0.97 respectively. Edward and Barber (1976b) reported on the influence of the shoot N requirement on the N influx per meter of maize root. They observed that increasing shoot demand for N does not immediately affect N influx into the root but that the capability for higher N influx is developed when plants are grown under N stress.

The fact that both mass flow and diffusion are involved in nitrate transport to maize roots has been demonstrated by Liao and Bartholomew (1974) who also reported that cultural conditions have a marked influence on active uptake of nitrate presumably through an influence on specific rates on N absorption. Influx characteristics of maize roots have also been studied by Claassen and Barber (1977) who observed that N influx is greater with the presence rather than the absence of potassium.

Soil tests for nitrogen: We expect soil tests to provide us with some indication of the availability of plant nutrients in the soil. However, Fox and Piekielek (1978a) reported the lack of a quick, reliable soil N availability test for soils of the humid regions. As such, N fertilizer recommendations in these areas are being made on the basis of crop N requirements. When the variability in the N supply capability of soils is not taken into account, most N fertilizer recommendations will be inaccurate, leading to inefficient use of N, less economical crop production, and the potential for N pollution of the surrounding air and water.

Fox and Piekielek (1978a) correlated eight N availability indexes with the capability of eight Pennsylvania soils to supply N to field grown maize. They found that four of the indexes were not significantly correlated with N availability in the field. The other four indexes were well correlated with N availability in the soil but the time and expense necessary for these analyses may preclude their being used routinely by soil testing laboratories. However, in seeking ways to shorten and simplify the analyses, Fox and Piekielek found in a later study (1978b) that ultraviolet absorption by the 0.01$\underline{M}$ $NaHCO_3$-soil extract at 260nm was as well correlated with the N supplying capability of the test soils ($\underline{r}$ = 0.865, $\underline{P}$<0.01) as the best of the eight previously evaluated N indexes. Fox and Piekielek (1978b) reported that this new method was rapid, simple and inexpensive, and demonstrated how the method could be used to predict more accurately the fertilizer N needs for maize.

Bar-Yosef and Akiri (1978) also used $NaHCO_3$ in their extraction study. They investigated the extractability of nitrate-N from five calcareous soils and reported that the amounts of extracted ions were related to (1) time since their application to the soils, (2) the equilibrium period of the soils with the extractants, (3) the concentrations of the ions in the soils and (4) the clay content of the soils. They noted that after about 70 days in the soil, the extractability of the ions at a given application level was independent of time.

While soil tests may indicate the level of availability of nutrients in soil, there is still a need to analyze selected maize tissues in order to monitor the actual nutritional status of the crop. The Diagnosis and Recommendation Integrated System (DRIS) utilizes ratios of tissue nutrient concentrations rather than the concentrations themselves. Escano et al. (1981b) evaluated several locally calibrated modifications of the DRIS and compared their diagnostic accuracies with those of a locally calibrated critical concentration approach. They calibrated both approaches and found that the DRIS approach was 8% more accurate than the conventional approach for the diagnosis of N deficiency.

Nitrogen in plant tissue: Apart from the diagnosis of nutritional problems, tissue analyses can be used to predict grain yields of maize. Escano et al. (1981a) evaluated several methods for determining adequate ranges and critical ear leaf concentrations for maize grown on Hydric Dystrandepts in Hawaii. They also reported highly significant positive correlations between tissue N concentrations and grain yield.

Pierre et al. (1977b) studied the relationship between N percentage in maize grain (N (grain)) and relative yield (RY), i.e., yield expressed as a percentage of maximum. They found that the RY-N (grain) relationship offers a promising and practical basis for estimating N sufficiency and the N requirement for maximum yield, of for an economically optimum yield. Following on from this, Pierre et al. (1977a) developed a procedure for determining the amount of N fertilizer needed by maize for maximum yields and economically optimum yield based on the RY-N(grain) relationship. The procedure employs three major steps: (1) the determination of the maximum potential yield and yield increase from the RY-N(grain) relationship, and the present yield, (2) the determination of the N-requirement index for different initial relative yields, and (3) the calculation of the total N requirement.

2.2.2. Phosphorous (P).

The quantities of P in the tissues of most plants are about one-tenth that of N and one-fifth that of potassium (K). However, for maize, a deficiency at the early stages of growth adversely affects the laying down of the primordia for the reproductive parts (Pleshkov, 1958 (Pleshkov, 1958). These adverse effects cannot be remedied by adequate P supplied at a later stage. Pierre and Pohlman (1933) reported that the phosphate concentration in the cell sap is frequently several thousand times higher than that in the displaced soil solution.

Soil P is present in the soil in amounts usually far lower than N and K - usually varying from 0.1 to 0.4 percent and rarely more than 0.5 percent (Seatz and Stanberry, 1963). Maize was found to make maximum growth at a concentration of 0.5 ppm in the soil solution provided this level was maintained throughout the growing period (Tidmore, 1930).

Response to Phosphorous: The importance of P in maize growth and yields has been reported by many workers working with maize on different soils. Kang and Yunusa (1977) (Oxic Paleustalf) reported increased root density of maize with P applications. Jones et al. (1982) (Vertisol) were able to quadruple maize yield by applying 80 kg P/ha. Kang and Osiname (1979) (Oxic Paleustaff) reported significant yield increases of maize with P applications of 26 to 52 kg P/ha depending on season and location. Fribourg et al. (1976) (Ultisols and Alfisols) observed that P uptake generally increased linearly with yield. Nicholaides et al. (1979) (Rhodic Paleudult) found that the greatest increase in maize grain yield was obtained with the first 28 kg P/ha and further response was linear at 200 kg/ha yield for each additional 28 kg P applied. Rehm et al. (1981) (irrigated sandy soil) reported that fertilizer P had a consistent effect on early plant growth, yield and maize maturity. They observed that the application of fertilizer P had a curvilinear effect on early growth and yield of maize with maximum yield produced with the application of 22 - 33 kg

P/ha. This compares with the findings of Moschler and Martens (1975) (Typic Paleudult) who reported that a three-year total rate of 67.3 kg P/ha gave the highest maize yield obtained. Black and Barel (1979) (Typic Haplaquoll) reported significant increases in maize yields from foliar (spray) applications of fertilizer P. In Hawaii Escano et al. (1981a) (Hydric Dystrandepts) found that maize had highly significant correlations between tissue P concentration and grain yield. Some workers, eg., Arnold et al. (1974) (Typic Paleudult), have reported that fertilizer P had little influence on maize yield. Such lack of response to P application indicate that soil P levels are already adequate for good maize production.

Phosphorous sources: The efficiency of fertilizer P in maize production may be influenced by the P source that is employed. This has been demonstrated by Mortvedt and Kamprath (1978) who conducted greenhouse pot experiments with maize grown on infertile soils to evaluate four fertilizers as sources of P. The granular sources were concentrated superphosphate (CSP), monoammonium phosphate (MAP) a 30/70 mixture of CSP AND DCP (dicalcium phosphate). The effectiveness of these P sources were found to be: MAP>CSP>30/70 mixture>10/90 mixture. Black and Barel (1979) (Typic Haplaquoll) reported that maize yields with foliar (spray) applications of tri-and tetraphosphate were, respectively, 760 and 754 kg/ha above the control yield of 10,234 kg/ha. They also compared several P-N compounds and condensed phosphate which were brushed onto maize leaves. In this experiment, phosphoryl triamide produced the highest yield of above-ground dry matter of maize plants.

Under certain conditions, some P sources may not show any significant differences as observed by Nicholaides et al. (1979). These authors compared pelletized ordinary superphosphate, concentrated superphosphate (CSP), and CSP coated with sulfur and a sealant. Yield responses of maize indicate that there are no significant differences among these three P sources.

The P source to be employed should also be considered with regard to the soil type on which maize is to be grown. For example, experimental results of Amer et al. (1982) indicate that diammonium phosphate may not be recommended for soils high in calcium carbonate content. Novias and Kamprath (1978) reported that in sandy Coastal Plain soils, the principal source of P removed by cropping was NH4F - P while in the clayey Piedmont soil, NH4F - P and NaOH - P supplied equal amounts.

Phosphorous application: Fertilizer P may be placed or applied in a variety of ways for maize production. It may be applied in the solid or liquid form. Solids may be broadcast or applied in bands, surface-applied in bands, surface-applied or deep placed. Phosphorous placement or methods of P application are important factors that may influence the efficiency of fertilizer P.

Kang and Yunusa (1977) (Oxic Paleustalf) reported that broadcast, hand and hill methods of P application were equally effective in supplying adequate P to maize crops at P rates of>20 kg P/ha. However, according to the observations of Chaudhary and Prihar (1974) (Typic Ustochrept), more-rapid early growth and higher grain yields of maize were associated with band placement of fertilizer nutrients. They reported that band application of fertilizer P increased maize yields by 40 percent when compared with broadcast application. Creamer and Fox (1980) found that the toxicity of banded diammonium phosphate to maize appeared to be due to root growth inhibition by ammonia toxicity around the band.

Experiments by Yost et al. (1979) (Typic Haplustox) indicate that the best method for applying P to high absorbing soils appears to be a large initial broadcast application and a small band application to each crop to maintain the available soil P at the critical soil test level. Cihacek et al. (1974) (Mollisols and Entisol) compared broadcast application with deep placement of P. Their data indicated that the two methods of P application gave comparable yields but deep placement resulted in less runoff of P and afforded greater season-long crop feeding on the fertilizer. Stryker et al. (1974) investigated the applications of nonuniform P distribution in the root zone of maize and reported that maximal dry matter accumulation occurred only when the entire root system was exposed to an external P supply. However, according to the calculations of Anghinoni and Barber (1980), as the volume fraction of P treated soil increased from zero, calculated P uptake increased to a maximum then decreased with further dilution of added P with soil.

Phosphorous availability in the soil and its uptake by maize plants may also be influenced by the application of other nutrient elements and by liming. Terman et al. (1977) reported that applied N also increased both P concentrations and uptake in young maize plants. Mendez and Kamprath (1978) (Latosols,>60% aluminum saturation) reported that at low rates of applied P, liming to neutralized Al significantly increased growth of millet (Pennisetum typhoides, var Gahi 1).

When fertilizer P is to be applied as foliar sprays, consideration should be given to the correct concentration to avoid damage to crop plants. In his work with various sources of fertilizer P, Newmann (1979) found that damaging concentrations of the foliar sprays on maize ranged from 3.8 to 11 g/litter. Black and Barel (1979) reported that the maximum spray concentrations of P tolerated by maize grown in the greenhouse are 1.3 percent for tri- and tetra-polyphoaphrwa, and 0.5% for orthophosphate.

With soil application of P the method or system of tillage employed for maize production may influence the efficiency of applied P. For example, Cihacek et al. (1974) reported somewhat higher maize yields with moldboard plowing then with chisel plowing, irrespective of P rate or placement. However, the main interest with regard to tillage systems seems to be the comparison between the effectiveness of minimum or no tillage and conventional tillage systems. Moschler and Martens (1975) (Typic Paleudult) reported that all rates of applied P (up to 181.6 kg p/ha), no tillage culture increased the efficiency of the applied P. Kang and Yunusa (1977) (Oxic Paleustalf) observed that with the minimum tillage treatment broadcast P was mainly concentrated in the upper 0.5 cm of the surface soil, and only moved slowly in the soil profile. However, high root density observed at shallow depth (0 - 10 cm) with minimum tillage enables maize plants to absorb sufficient amounts of surface broadcast P judged from P uptake and maize yields. This confirms the findings of Fink and Wesley (1974) (Typic Hapludalf, Aquic Argidoll) who reported that surface application of P is a satisfactory method of meeting the P needs of maize plants grown under no-tillage systems.

Phosphorous interactions: Several workers have reported the interaction of P with (Zn) in maize. This P - Zn interaction has also been reported in other plants such as soybean (*Glycine max* Mer.) (Lambert et al., 1979), and subterranean clover (*Trifolium subterraneum* L.) (Loneragan et al., 1979). Christensen and Jackson, (1981) found that yield and tissue concentration of P and Zn were affected by statistically significant P - Zn treatment interactions in maize. Experimental results of Kang and Osiname (1979) (Oxic Paleustalf) showed that the Zn status in the ear leaf of maize was depressed by high rates of P application. In greenhouse experiments, Safaya (1976) (Loamy sand) reported that visual symptoms of Zn deficiency appeared in maize plants when the level of applied P was raised to 75-Ug P/g soil. He found that P decreased tissue - Zn flux through roots. Lambert et al. (1979) observed that, in maize plants, the reduction of Zn concentration by P fertilization was significantly greater for mycorrhizal plants then for nonmicorrhizal ones.

Organic residues may play an important role in the P nutrition of maize. Kang and Osiname (1979) (Oxic Paleustalf) reported significant responses to P application on maize grown on newly cleared land when fallow residue was removed and no P response when fallow residue was retained and burned in the plot. Results of a study by Singh and Jones (1980) suggest that P fertilizer rates estimated from Abbot (1978) suggested that extractable organic P may be included in the P evaluation of a given soil depending on (1) time of sampling, (2) crop to be grown, (3) the method of extraction and (4) the means of converting organic P into a measurable inorganic form in the extract.

Soil tests for Phosphorous: A number of soil P tests have been reported in the literature. Kang and Osiname (1979) (Oxic Paleustalf) reported on the good relationship between the Bray P - 1 values and maize grain yield. In a greenhouse experiment, Holford (1980) evaluated 4 soil P tests (Olsen, Colwell, Bray and Mehlich) on 30 soils varying in pH from 5.4 to 8.1. He found that the Olsen and Colwell tests were the most highly correlated with plant uptake, and the Olsen and Bray tests were the most correlated with relative yield. His results showed that in a successful soil test, increasing buffer capacity will depress the extraction of labile P in the same way it depresses uptake by plants. Data from a study by Adepoju et al. (1982) suggests that the estimation of quantities of available P from soil analysis might be highly dependent on soil characteristics and the nature of the P compounds that have accumulated. Bar-Yosef and Akiri (1978) studied the extractability of P by $NaHCO_3$ (0.5 M, pH 8.5) from five calcareous soils. They related the extracted amount of P, as for nitrate-N to the (1) time since its application to the soil (2) equilibrium period of the soils with extractants, (3) concentrations of the ions in the soils and (4) clay content of the soils. After about 70 days in the soil, the extractability of P at a given application level was found to be independent of time. The recovery percentage of P as a function of the applied amounts of P was reported to be dependent mainly on the clay content of the soils .

Phosphorous in plant tissue: Escano et al. (1981b) evaluated several locally calibrated modifications of DRIS and compared their diagnostic accuracies with those of a locally calibrated critical concentration approach. They found that the two approaches were almost equally accurate for the diagnosis of P deficiency in maize. (The DRIS was actually 2% more accurate than the best locally-calibrated critical concentration approach). With maize, the nutrient composition of the ear leaf at tasselling or silking has been widely used in estimating the nutrient status of the crop (Rehm et al., 1983). As such Kang and Osiname (1979) (Oxic Paleustalf), estimated that the critical P in the ear leaf at silking is 0.3% P. The corresponding values estimated by Rehm et al. (1983) on a sandy soil were 0.220 percent P (silage harvest system) and 0.225% P (grain harvest system). However, Rehm et al. (1983) argued that the addition of a fertilizer to correct a discovered nutrient deficiency is very difficult, if not impossible, at this late stage of growth, ie., at silking. They suggested that the development of "critical" levels of plant nutrients in maize tissue at earlier stages of plant development should be more practical and useful. As such, they collected whole plant samples when the maize was only 40 to 60 cm tall. They found that in the whole plant samples at this early growth stage, the critical P values were 0.220 percent P (silage harvest system) and 0.256 percent P (grain harvest system).

Genotype effects on response to P: Schenk and Barber (1979) have suggested that the utilization of P applied to soils may be increased by having more roots present or by improving P uptake characteristics of the roots. Their studies indicated that the amount of P absorbed by maize is influenced by differences between genotypes with regard to morphological and physiological root characteristics. Such findings suggest that genotypes could be developed that would be more efficient in absorbing P from soil. The fact that many plant species utilize fertilizer or soil P inefficiently has been mentioned by Nielsen and Barber (1978) who affirmed the importance of developing genotypes that are more efficient in absorbing P from soil. In an earlier study, Terman et al. (1975) reported that nutrient absorption among crop cultivars is genetically controlled. Furthermore, they observed that these differences in nutrient absorption appear to be greatly influenced through genetic effects on growth rates and yield potentials.

2.2.3. Zinc (Zn).

Viets et al. (1953) found that 15 ppm Zn in the sixth leaf of maize, at the time pollen is shedding, appears to be an adequate level for yields in the range of 6700 to 8400 kg/ha. However, Brown and Krantz (1966) obtained their highest yields of maize with Zn levels of only 6.5 ppm. Investigations by Fuehring and Soofi (1964) appear to indicate that the response of maize to Zn is directly opposite between vegetative and storage parts of the plant. On a calcareous clay loam in Michigan, yields of maize were increased from 8250 kg/ha to 9550 kg/ha by an application of 4.4 kg/ha Zn as $ZnSO4$ (Roscoe et al., 1964). A crop of maize producing 18.7 tons/ha of dry matter accumulated only 440 g Zn/ha .

Water-soluble Zn is practically non-existent in the soil, while that in exchangeable form is usually $<$ 1ppm (Olson and Lucas, 1966). For normal maize growth, the required concentration in the soil solution is probably only 0.1ppm (Thorne, 1957) Zinc availability declines with increased pH (Camp, 1945). Zinc deficiency is being encountered with increasing frequency as a result of increased use of lime, large applications of high analysis of fertilizers, and the high yields obtained by growing productive hybrids with improved cultural practices (Arnon, 1974).

2.2.4. Copper (Cu).

Maize has been found capable of developing into mature plants on an organic soil with a Cu content of 11 ppm. Wheat under the same conditions failed completely (Brown and Harmer, 1950). A mature crop of maize, producing 8.7 tons/ha dry matter, contains only 199 g/ha Cu (Benne et al., 1964).

Copper contents of most soils are very low. However, since soil fixation is minimal, deficiency problems in maize are extremely rare. Copper deficiencies are most likely to appear on acid, highly leached sandy soils and on calcareous sands, especially if they contain considerable organic matter (Olson and Lucas, 1966). Crops do not respond to Cu fertilization if soils contain >20 ppm Cu (Lundblad et al., 1949).

III. MATERIALS AND METHODS.

3.1. Experimental Soil.

This experiment was carried out at the Poamoho Farm of the University of Hawaii Agricultural Experiment Station on the island of Oahu, Hawaii (150m to 210m elevation). The soil of the experimental site has been described by El-Tahir (1976):

> The experimental soil belongs to the Wahiawa Series which is the clayey, kaolinitic, isohyperthermic Family of the Tropeptic Eutrustox subgroup of the Oxisols. This is found at elevations around 200m on Oahu. They are well-drained soils developed in old alluvium derived from basic igneous rock on nearly level to moderately steep slopes. Annual rainfall ranges from 1000 mm to 1500 mm and the annual mean soil temperature is around 22^{o}C. The surface layer is very dusky-red to about the 30 cm depth, while the subsoil is dark-reddish brown and is about 118 cm deep. This soil is usually used for growing sugarcane and pineapple. The natural vegetation includes Bermuda grass, guava, and lantana.

Representative surface soil (0 - 15cm) samples of each of the 54 plots of the experiment were taken after cultivation but before fertilizer application and planting to provide information on the initial fertility status of the experimental soil. A summary of the results of the analyses of these samples is shown in Table 3.1. Three soil profiles (one per rep) were also taken, to a depth of 105cm. The profiles were actually taken after planting but they were taken from areas outside the plots which had not been fertilized or planted to simulate as well as possible the initial preplanting conditions. A summary of the profile-sample analyses is shown in Table 3.2. The detailed soil analysis for each plot is presented in Appendix C.

Phosphorous was analyzed by the modified Truog and Olsen's methods. Zinc, Cu and N (NH_4 + NO_3) were analyzed according to Black et al. (1965) while the other soil analyses followed the procedures of the Soil Conservation Service of the U.S. Department of Agriculture.

3.2. Experimental Plan.

3.2.1. Treatments.

The basic treatment design was the 2^5 partial factorial modification according to Escobar which had 13 treatments. Additional treatments were added to assess the yield potential of the site without fertilizers, to assess the deletion of Zn and Cu from the blanket fertilizer, determine if maximum yield could be attained with a higher population, and with the addition of chicken manure. The 18 treatments studied in this experiment are shown in Table 3.3.

Table 3.1. Chemical Analysis (Mean Values) of Preplant Surface Soil (0-15 cm) Samples from Experimental Site.

Analyses	Mean	Std Dev[a]	Range
Mod Truog P (mg kg^{-1})	31.91	9.67	12.17-48.49
NH_4-N (mg kg^{-1})	14.66	3.85	4.81-23.10
NO_3-N (mg kg^{-1})	4.05	3.42	0.00-11.58
1:1 H_2O pH	5.57	0.18	5.15-5.95
1:1 KCl pH	5.02	0.12	4.77-5.26
Ca (cmol (+) kg^{-1})	5.15	0.71	3.79-6.35
Mg (cmol (+) kg^{-1})	1.18	0.17	0.86-1.52
Na (cmol (+) kg-1)	0.17	0.02	0.13-0.22
K (cmol (+) kg^{-1})	0.84	0.24	0.32-1.46
Cu (mg kg^{-1})	0.40	nd	0.34-0.53
Zn (mg kg^{-1})	0.25	nd	0.06-0.25

[a]nd = not determined.

Table 3.2. Chemical Analysis (Mean Values) of Profile Samples from Experimental Site.

	........................DEPTH (cm)..................						
Analyses	0-15	15-30	30-45	45-60	60-75	75-9	Table 3.5.
Experimental Treatments.							
pH (H_2O)	5.18	5.33	5.52	5.57	5.68	5.78	5.84
pH (KCl)	5.03	4.99	5.32	5.38	5.50	5.63	5.68
	($mg\ kg^{-1}$)						
Mod Truog P	18.56	13.36	1.69	1.04	1.62	1.12	0.49
NH_4-N	6.28	4.15	4.05	3.65	0.83	0.00	0.00
NO_3-N	7.77	0.00	0.00	0.00	0.00	0.00	0.00
	(cmol (+) kg^{-1})						
Ca	4.23	4.20	3.75	3.56	3.56	3.49	3.38
Mg	1.12	1.14	1.04	1.29	1.38	1.60	1.79
Na	0.23	0.14	0.13	0.14	0.16	0.17	0.20
K	0.65	0.72	0.34	0.27	0.29	0.15	0.13

Table 3.3. Chemical Analysis of Chicken Manure.

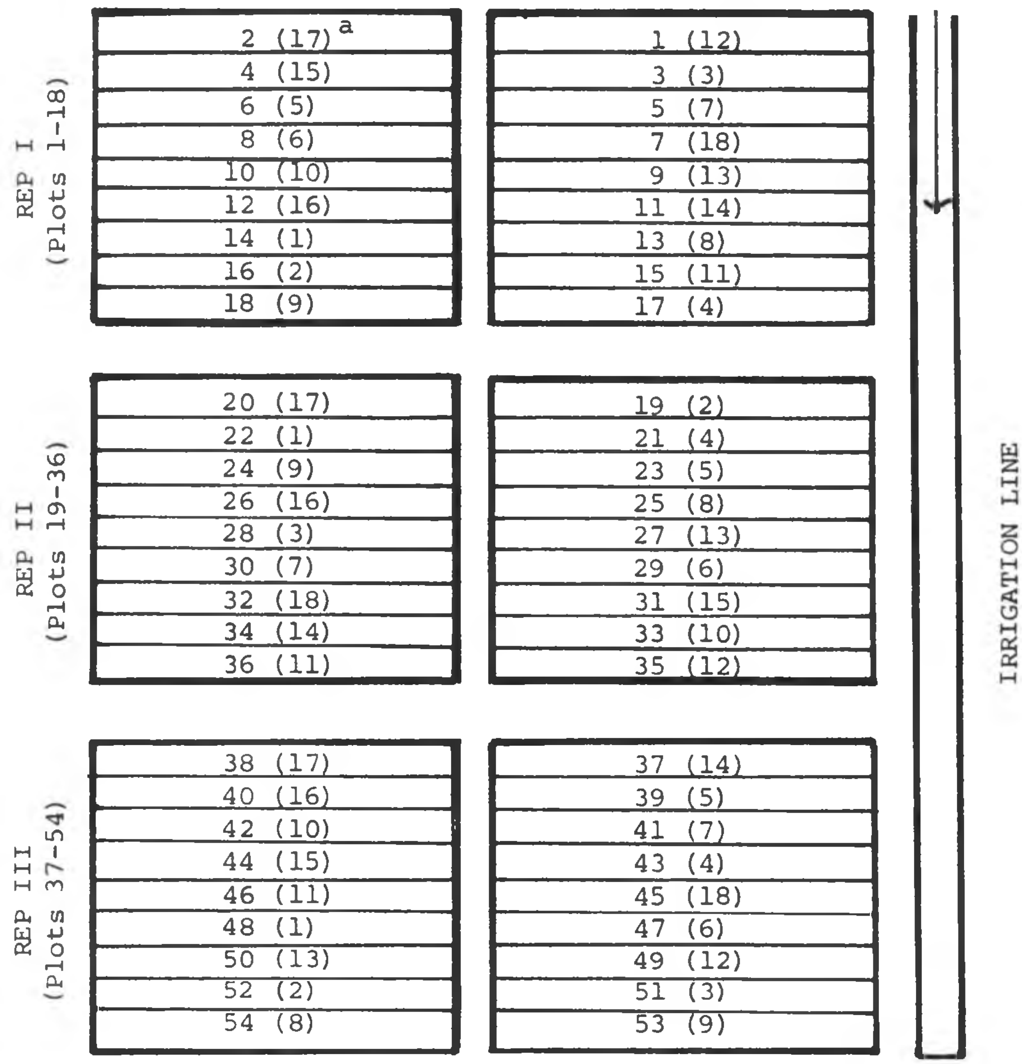
ANALYSIS	CONCENTRATION ($mg\ kg^{-1}$)
Modified Truog P	4372.20
Total N	18400.00
Cu	0.70
Zn	4.58
Ca	1830.00
Mg	98.80
Na	67.40
K	428.80

3.2.2. Experimental Design.

The 18 treatments (Table 3.5) were replicated three times for a total of 54 plots installed in a Randomized Complete Block Design as shown in Figure 3.1. As illustrated in Figure 3.2, each plot had four rows for a total area of 42 m^2 (14m x 3m). The two inner rows, apart from the 1m guard areas at either end of the plot, were used for the final harvests and also for taking height measurements and ear leaf and biomass samples. Distances between rows were maintained at 75cm while distances between plants in a row were manipulated to give two planting densities. The higher planting density of treatment #17 (Table 3.5) was effected by reducing the inter-plant distances within the rows from an average of 19.6cm to 14.2cm.

Table 3.4. Full Blanket Application.

Nutrient Element	kg ha^{-1}	Source of Nutrient
K	100.0	Muriate of Potash
Zn	15.0	Zinc Sulphate
B	5.0	Borax
Cu	2.5	Copper Sulphate



[a] Plot number,(Treatment number).

Figure 3.1. Field Layout for N x P Fertility Experiment

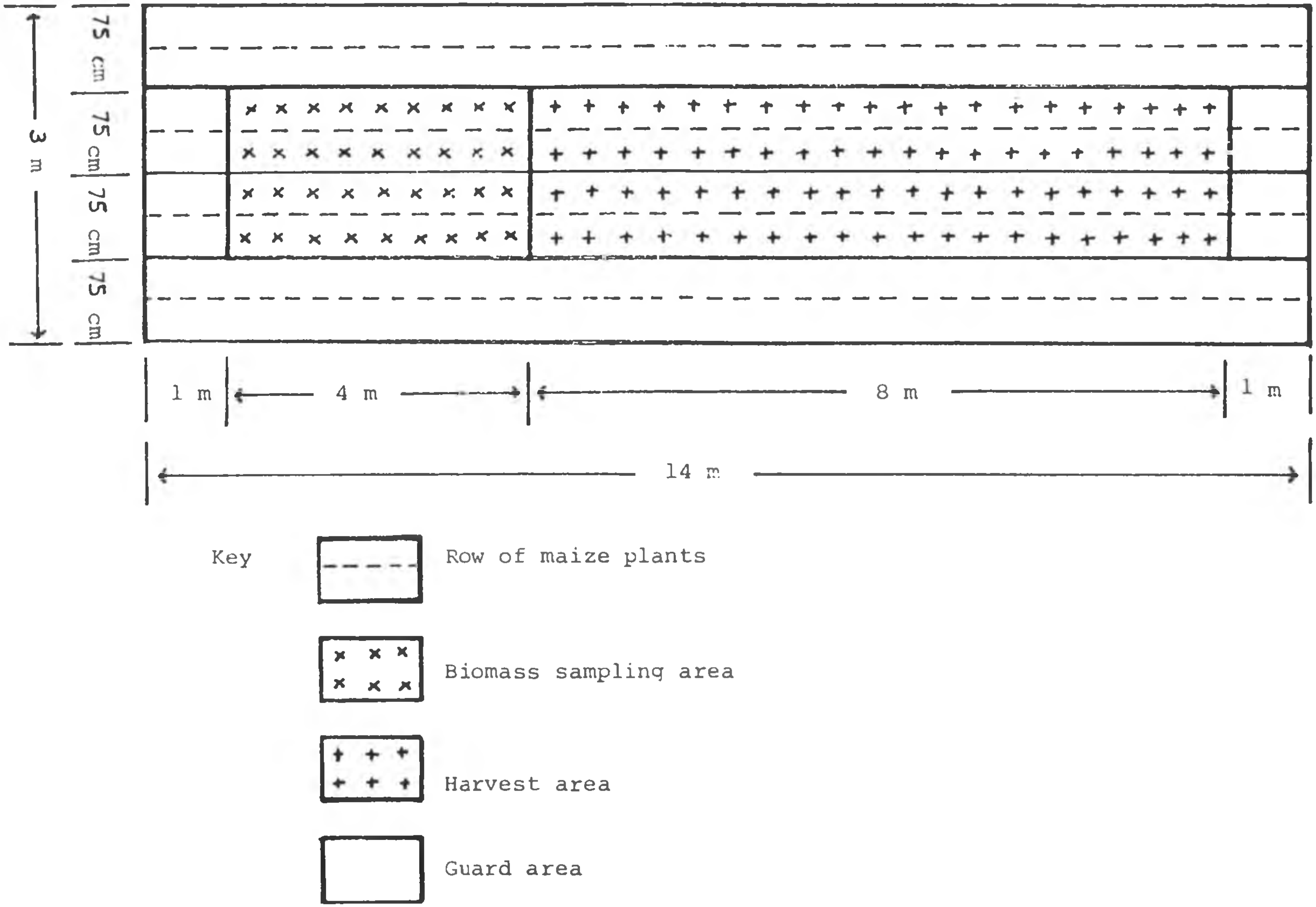


Figure 3.2. An Experimental Plot

Table 3.5. Experimental Treatments.

Treatment no.	(..kg ha^{-1}.) N	P	Blanket Application[(a)]	Planting Density[(b)]	Chicken Manure[(c)]
1	0	0	0	1	0
2	0	0	1	1	0
3	0	100	1	1	0
4	0	200	1	1	0
5	50	50	1	1	0
6	50	150	1	1	0
7	100	0	1	1	0
8	100	100	1	1	0
9	100	200	1	1	0
10	150	50	1	1	0
11	150	150	1	1	0
12	200	0	1	1	0
13	200	100	1	1	0
14	200	200	1	1	0
15	200	200	1-Zn	1	0
16	200	200	1-Cu	1	0
17	200	200	1	2	0
18	200	200	1	1	1

a. 1 = blanket application described in Table 2; 0 = no blanket application; 1-Zn = partial blanket application without Zn; 1-Cu = partial blanket application without Cu.

b. 1 = average planting density of 67,800 plants ha^{-1}; 2 = planting density of 93,900 plants ha^{-1}.

c. 1 = 16.82 Mg ha^{-1} fresh chicken manure (14.7% moisture); 0 = no chicken manure.

3.3. Cultural Practices.

3.3.1. Land Preparation.

The experimental area was disced, ripped, plowed, and rotovated to a depth of 40 cm before planting. However, a portion of the first replicate (plots #1 to 12) was neither plowed nor rotovated but was only disced and ripped due to a breakdown of machinery.

3.3.2. Planting.

Maize seeds of Pioneer variety X304-C were treated with isotox before planting to discourage birds from eating them. Planting was done on April 30, 1985 by hand with jabbers which set the planting distance and positioned the seeds properly in the hill. Two seeds were planted per hill. Germination was checked at 6 DAP and blank hills were replanted at that time. The crop was thinned to one plant per hill at 14 DAP when plants were at the 4-leaf stage.

3.3.3. Fertilizer Application.

All nutrients were applied by hand and incorporated into the soil before planting with a hand-operated rototiller to a depth of 15 cm. One-third of the N was applied at planting while the other two-thirds was later side-dressed in two equal amounts. The first side-dress application was at four weeks after 50% emergence while the second side-dress application was made at the first indication of tasselling.

3.3.4. Control of Weed and Insect Pests.

Since weed and insect pests were not considered as variables in this experiment they were strictly kept under control over the whole experimental area. A mixture of alachlor (Lasso) and Paraquat (Gramoxone) was applied as a pre-emergence herbicide while Lorox was used for weed control after the maize plants were 35 cm high. Furadan granules were applied at planting to protect seedlings from insect infestation and a postplant application of Diazinon was used to control cutworms. There was no serious disease infestation.

3.3.5. Irrigation.

Water was provided to the maize crop via furrow irrigation. Irrigation was another factor that was not a variable in this study; therefore, optimal quantities of water were supplied, once or twice a week, depending on weather conditions, to all plots to prevent water stress.

3.3.6. Harvest.

The crop was harvested when each plot reached physiological maturity. Ears were removed from all plants in the 8m harvest area of the two harvest rows and stalks were cut at ground level. Weights of ears and stover were recorded and samples of ten randomly-selected ears and stalks were collected from each plot for additional measurements.

3.4. Data Collection, Management and Analysis.

3.4.1. Data Collection.

3.4.1.1. Phenological Data.

Plant Height and Growth Rate of Plant Height: Plant height measurements were taken at 24, 57 and 119 days after planting (DAP). At 57 DAP, none of the maize plants had tasselled while at 119 DAP all of them had silked. Five plants per harvest row (10 per plot) were measured for plant height. These 5 plants were the 3rd, 6th, 9th, 12th, 15th and 18th plants of each harvest row counting from the inner end of each harvest row (Figure 1). The average height of the ten plants was taken as the average height for the plot.

The growth rates of plant heights were calculated from the three height measurements above using the formula:

$$\text{Growth Rate} = \frac{(\text{Height B}) - (\text{Height A})}{\text{DAP(B)} - \text{DAP(A)}}$$

where "A" refers to the earlier measurement and "B" to the later measurement; "DAP" stands for "days after planting".

The following six growth rates were calculated:

Growth Rates	From:	To:
1.GRA	Planting	Height A
2.GRB	Planting	Height B
3.GRC	Planting	Height C
4.GRAB	Height A	Height B
5.GRAC	Height A	Height C
6.GRBC	Height B	Height C

where "A" refers to the first, "B" the second and "C" the third height measurements.

Biomass and Growth Rate of Biomass: Above-ground biomass samples were taken at the following three stages of crop growth: 31 DAP, 73 DAP and when 50% of the maize plants had grain in the dough stage. At each sampling, eight maize plants were harvested from the biomass sampling area (Figure 2) of each plot. One plant per tier was left standing between each successive biomass sample to minimize border effects.

At the third sampling, the biomass samples for each plot were separated into stover and ears, and were chopped, dried, weighed, and analyzed separately.

Growth rates of biomass were calculated from data from the three biomass samples by the following formula:

$$\text{Biomass Growth Rate} = \frac{(\text{Biomass Weight B}) - (\text{Biomass Weight A})}{\text{DAP(B)} - \text{DAP(A)}}$$

where "A" refers to the earlier biomass sampling and "B" to the later one.

The biomass growth rates calculated are shown below:

Biomass Growth Rates	From:	To:
1. BGRA	Planting	Sampling A
2. BGRB	Planting	Sampling B
3. BGRC	Planting	Sampling C
4. BGRAB	Sampling A	Sampling B
5. BGRAC	Sampling A	Sampling C
6. BGRBC	Sampling B	Sampling C

Tasselling and Silking: Days to 50% tasseling is the number of days required for 50% of the plants in the plot to reach the tasseling stage, and days to 50% silking is the number of days required for 50% of the plants in the plot to reach the silking stage. Days between tasseling and silking were determined by subtracting "Days to 50% Tasseling" from "Days to 50% Silking".

Ear Leaf Samples: Ear leaf samples were taken when 50% of the plants in a plot had silked. Five ear leaves were collected from each harvest row in a plot giving a total of ten ear leaves per plot. These leaves were oven dried at 70°C, ground in a stainless steel Wiley Mill, then used for the determination of nutrients in the ear leaves. The oven dry weights of the leaves were also recorded to compare the effects of the treatment variables on ear leaf weights.

Dead Leaf Count: A count of dead leaves was made at 90 DAP when all but the 0-N plots (i.e., plots of treatments #1 to 4) had silked. The 6th plant in each harvest row (2 plants per plot) was used in the count. Numbering of plants started from the inner end of each harvest row. "Dead Leaves" refers to the total number of dead leaves counted on these two plants per plot.

Crop Greenness: The greenness of maize plants was evaluated at 95 DAP when 50% of the plants in the last plots to tassel (i.e., the complete control plots) were at the silking stage. This response variable was measured to assess the effects of the input variables, especially N, on the greenness of the maize plants. The following scale was used in this determination:

Value	Crop Color
1.0	Yellowish Green
1.5	Between Green and Yellowish Green
2.0	Green
2.5	Between Green and Dark Green
3.0	Dark Green.

Crop color was determined for each plot by evaluating the overall color of the leaves in the plot.

Crop Brownness: This plant color was evaluated at 130 DAP when the first plots reached physiological maturity. The measurement was made to determine the relative effects of N and P on leaf necrosis at maturity. The following scale was used in this determination:

Value	Crop Color
1.0	Green
1.5	Between Green and Brownish Green
2.0	Brownish Green
2.5	Between Brownish Green and Brown
3.0	Brown.

Crop color was determined for each plot by evaluating the overall color of the leaves in the plot.

Days to Physiological Maturity: Physiological maturity was determined by the "black layer technique" as described by the Benchmark Soils Project Staff (1982). The presence of the black layer was determined by breaking a maize ear in half, removing a kernel from the central portion of the cob, and breaking off the kernel's tip with the thumb nail. The kernel was said to have a black layer if a dark area was easily visible near the kernel tip. With this technique, an individual ear was considered to have reached physiological maturity when at least 75% of the kernels in the central part of the ear had black layers, while a whole plot was considered to have reached physiological maturity when three sampled ears had reached physiological maturity.

3.4.1.2. Yield Data.

Ears and stover were harvested from the two harvest rows in each plot when the maize plants reached physiological maturity. A sample of harvested ears was taken for the determination of filled earlength, 100-kernel weight and grain moisture.

Grain Yield, Filled Earlength and 100-Kernel Weight: The total weight of the ears collected from the harvest rows was determined in the field. Then ten ears were randomly picked for additional measurements. In the laboratory, these ten ears were weighed, and shelled and the weight and moisture content of the shelled grain were determined. The maize grain yield of the plot was expressed as Mg ha^{-1} at 15.5% moisture for a plant population of either 67,800 or 93,900 plants ha^{-1}, depending on treatment.

The ten-ear sample was also used for the determination of the filled earlength and 100-kernel weight at 15.5% moisture (from two samples of 100 kernels each).

<u>Stover Yield</u>: Stover was cut at ground level and the weight of stover per plot determined in the field. Ten plants were randomly picked for additional measurements. The ten plant sample was weighed and chopped in a forage chopper. A subsample of the chopped material was taken, weighed, oven dried and reweighed. The stover weight of the plot was expressed as Mg ha^{-1} on the oven dry weight basis for a population of either 67,800 or 93,900 plants ha^{-1}, depending on treatment.

3.4.1.3. Nutrient Content of Plant Tissue.

Plant tissues were analyzed to determine the concentrations of various mineral elements. A quantometer (Applied Research Laboratories, Model 72000, Fluorescence Quantometer) was used for the determination of P, K, Ca, Mg, S, Si, Cl, Al, Mn, Fe, and Zn. The quantometer's detector was not working for Cu which had to be determined by atomic absorption (AA) with a Perkin Elmer AA instrument. Nitrogen was determined by colorimetric analysis of acid-digested samples with a Technicon Autoanalyzer. These analyses were carried out on ear leaves sampled at 50% silking and also on the biomass samples collected at 31 and 73 DAP and when grain was at the dough stage. Due to time limitations, results of the biomass tissue analyses are not statistically analyzed in this thesis.

3.4.1.4. Soil Analysis.

Three soil samples were collected for this study. The first sample was collected after land preparation but before basal fertilizer application and planting. Four subsamples were collected and composited for each plot. All 54 plots were sampled at the 0-15cm depth and analyzed for P (Modified Truog and Olsen's), N (NH_4-, NO_3- and total-N), organic C, pH (1:1-H_2O and -KCl), Ca, Mg, Na, K, Cu and Zn.

The second sample was collected to provide information on the soil profile prior to land preparation. The profiles were actually taken after planting but they were taken from areas outside the plots which had not been fertilized or planted to simulate as well as possible the initial preplanting conditions. Soil samples were taken at 15cm intervals, from 0 to 105cm. Samples from three profiles were obtained from areas representing each of the three replicates. The analyses carried out were similar to those done for the first sample except that samples were not analyzed for Olsen's P, Zn, and Cu.

The third sample was collected immediately after harvest to provide information on the post-harvest status of the soil. As for the first sample, four subsamples were collected from the 0 - 15 cm depth and composited for each plot. The analyses carried out were the same as for the first sample except that the concentrations of Olsen's P, total N, and organic C were not determined

3.4.1.5. Meteorological Data.

Meteorological data for the maize growing period were collected and are presented in appendix - to provide information on the environmental conditions that prevailed during the crop's growth. Data were collected with a rain gauge, max-min thermometer, pyranometer, and an evaporimeter to measure rainfall, temperature (maximum and minimum), solar radiation and evaporation, respectively.

3.4.2. Data Management.

Data from field and laboratory measurements were recorded directly into field notebooks acquired for this purpose. However, data collected during the final harvests and data for the soil and tissue analyses were entered into tabular forms prepared for this purpose. Meteorological data were copied from forms obtained from the Poamoho Experimental Farm. Selected data were stored on an IBM Personal Computer diskette and were organized and managed with the Lotus 1,2,3 Program.

3.4.3. Data Analysis.

Data were analyzed by analysis of variance and regression techniques on an IBM Personal Computer using the STAN program. STAN is an "interactive" statistical analysis system for microcomputers.

IV. RESULTS AND DISCUSSION.

Data collected and analyzed in this experiment were for phenology (to describe plant morphology and growth), yields (to describe grain and stover yields at final harvest), ear leaf nutrients (to describe mineral concentrations in ear leaves) and soil nutrients (to describe, among other things, the effects of experimental variables on the final fertility status of the soil).

Experimental data were divided into three groups (A, B and C) for statistical analysis. The first group, A, included data for the first two treatments, treatments #1 and 2 - the complete and partial controls, respectively. The main purpose of statistical analyses of data in group A was to determine the effects, if any, of the blanket treatment.

The second group, B, included data for treatments #2 to 14. These 13 treatments received differential amounts of N and P and, therefore the main purpose of statistical analyses of data in group B was to determine the effects, if any, of N, P, and their interaction on plant growth and yield parameters.

The third group, C, included data from treatments #14 to 18 which received the highest N and P treatments with several additional treatments including -Zn, -Cu, high planting density, and chicken manure. The main purpose of statistical analyses of data in group C was to determine the effects, if any, of Zn, Cu, planting density and chicken manure on growth and yield parameters of maize.

Results of analyses for Group B are discussed under "2.1 Responses to Nitrogen and Phosphorous" while analyses for Groups A and C are discussed under "2.2 Responses to the Supplementary Treatments".

4.1. Phenology, Yield and Ear Leaf Analysis.

4.1.1 Response to Nitrogen and Phosphorous.

Responses by the measured dependent variables were, in all cases, greater for N than for P. Furthermore, most of the responses to N were statistically significant while most of the responses to P were not significant. However, because of the nature of the experiment, it is difficult to discuss the effect of applied N without referring to applied P; so the effects of the two input variables will be considered together in the discussion of results.

All application rates of N and P are in kg ha^{-1} so application rates of, say, 100kg N ha^{-1} and 200kg P ha^{-1} will be simply referred to as 100N and 200P, respectively throughout the thesis.

Quadratic regression models are used in this discussion to provide some measure of the importance of N, P, and their interaction on the measured dependent variables. The three quadratic models used are the N, P, and NP quadratic models which will be simply referred to as the N model, the P model, and the NP model. The N model is defined as:

$$Y = b_0 + b_1N + b_2N^2,$$

the P model as:

$$Y = b_0 + b_1P + b_2P^2$$

and the NP model as:

$$Y = b_0 + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP.$$

4.1.1.1. Final Harvest.

Grain and stover yield were the harvest variables of major interest, while filled earlength and weight of 100 kernels were of secondary interest. The relative effects of applied N and P on these variables (as indicated by R^2) are evident in Table 4.1. With all of these variables, applied N had a greater effect (R^2 = 0.463 to 0.953) than applied P which had R^2 values of 0.002 to 0.021. Nitrogen was thus the more limiting of these two nutrients, which is in agreement with the initial modified Truog soil P values of 12.2 to 48.5 mg kg^{-1} (mean = 31.9 mg kg^{-1}, standard deviation = 9.7) for the experimental area. A Modified Truog P level of 25 mg kg^{-1} is considered adequate for maize growth.

Table 4.1. R Square Values for Final Harvest Variables of Maize with Three Regression Models.

Quadratic	R Square Values			
Model	Grain Yld	Stover Yld	Filled Earlength	100 Kernel Wt
N	0.953	0.782	0.924	0.463
P	0.002	0.004	0.006	0.021
NP	0.955	0.791	0.935	0.501

Grain yield increased from 0.96 Mg ha^{-1} without N or P to 12.15 Mg ha^{-1} with 200 N and P (Figure 1). The increase, predominantly due to N, was large to 100N and then more gradual to 200N. There was no significant N x P interaction as the MSE value of the NP model did not differ significantly from that of the N model (Appendix 1A). However, yields were higher with 0 and 200N at 200P than at 0P or 100P. This apparent yield response to P was not statistically significant.

At 100N, grain yield with 200P, treatment 9, was lower than with 0P, treatment 8, and 100P, treatment 7, (Figure 4.1). This trend may be the result of the low soil N in treatment 9 (Table 4.2) which was probably also responsible for the treatment's low stover yield (Figure 4.2) and low ear leaf N concentration (Table 4.3).

Treatment 9 had the lowest level of preplant, total, soil N; a treatment mean of 13.10 mg kg^{-1} compared to the experimental mean of 18.77 mg kg^{-1}. Since N was the most important element affecting grain yield, the unusually low level of soil N in treatment 9 is likely to have contributed to the low grain yield even though the treatment received the highest rate of applied P (Figure 4.1).

Results of this experiment show that grain yield is mainly a function of applied N. Even though applied P appeared to have some influence on grain yield, statistical analysis of MSE values (Appendix A1) indicated that this influence was not significant. This confirms earlier observations such as those made by Perry, Jr. and Olson (1975) who reported that maize grain yields increased significantly with 90N and 180N on a Typic Argiudoll in Nebraska, and by Grove et al. (1980) who found that grain yield increased significantly with the application of 60 to 220N on a Typic Haplustox in Brazil. Grove et al. (1980) commented that there appears to be no

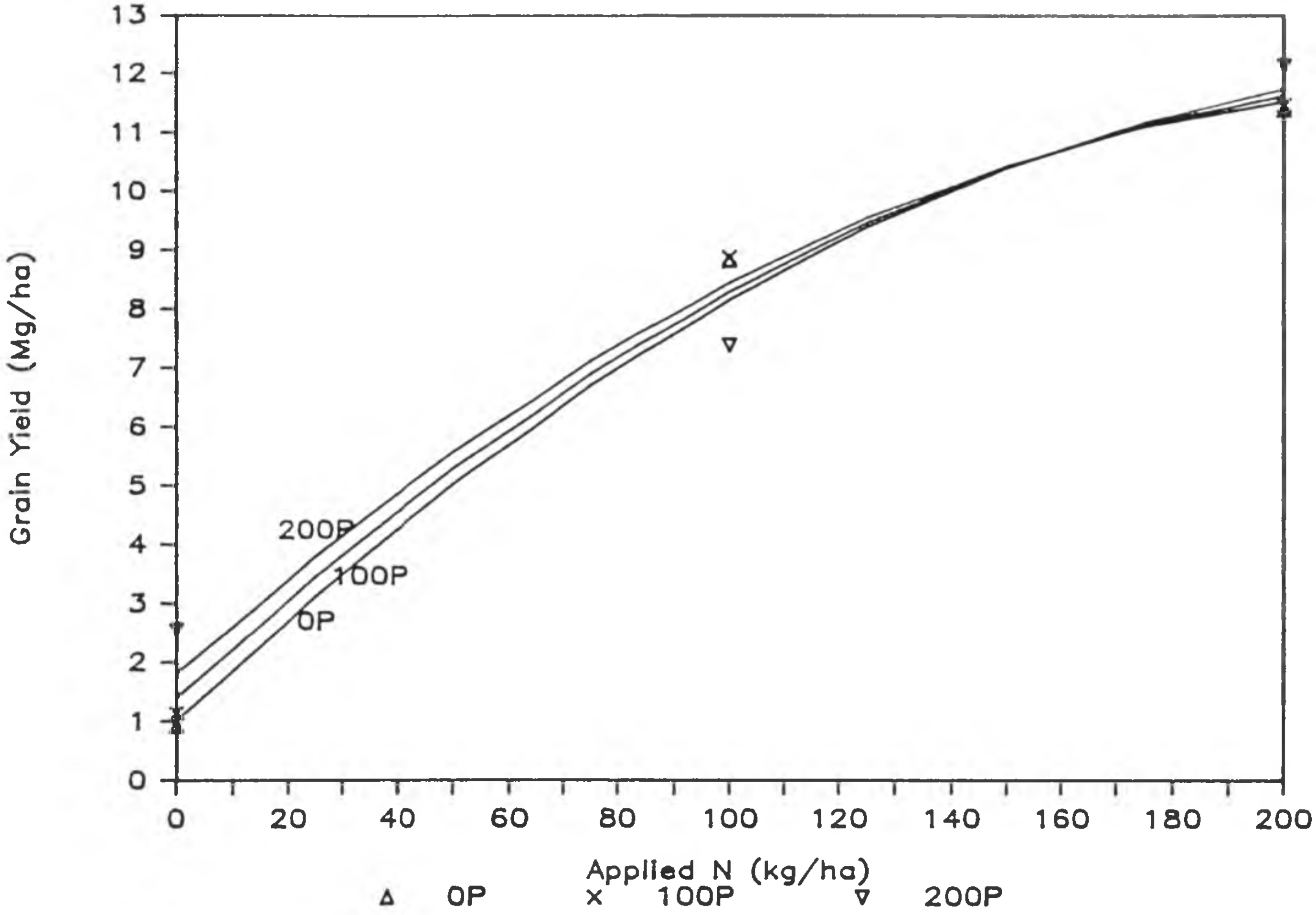


Figure 4.1. The effect of applied N and P on maize grain yield.
(R^2 = 0.96. Refer to Appendix B for regression coefficients.)

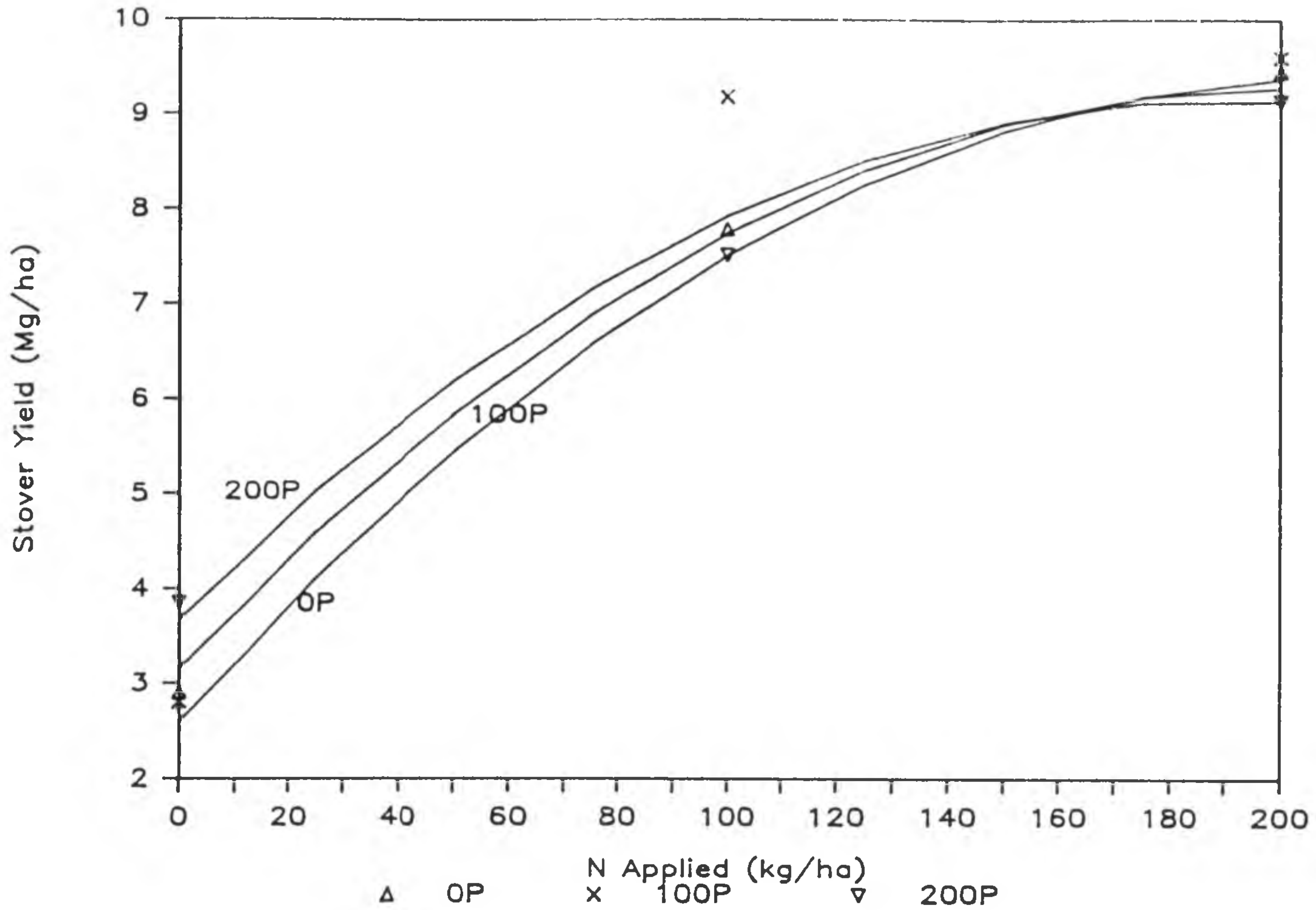


Figure 4.2. The effect of applied N and P on maize stover yield.
(R^2 = 0.79. Refer to Appendix B for regression coefficients.)

fundamental difference in response of maize to N fertilizer between Oxisols and soils of the temperate regions.

Stover yield increased from 2.9 Mg ha^{-1} without N or P to 9.1 Mg ha^{-1} with 200 N and P (Figure 4.2). The increase, predominantly due to N, was large to 100N and then more gradual to 200N. Applied P did not significantly modify the response to N since the MSE values for the N and NP models were not significantly different (Appendix A1). As discussed for grain yield, the unusually low level of soil N of treatment 9 probably resulted in lower stover yield than expected for 100N and 200P (Figure 4.2).

Filled earlength increased from 7.7cm without N or P to 18.4cm with 200N and P (Figure 4.3). The increase which was mainly due to N was large to 100N and then more gradual to 200N. Applied P appeared to modify the response to N somewhat because the NP model had a higher R^2 value (Table 4.1) and a lower MSE value (Appendix A1) than the N model. This may be seen in Figure 4.3 in which low P rates (0 and 100P) produced shorter earlengths than 200P at 0 and 200N. With 100N and 200P, filled earlength was shorter than expected because of the treatment's unusually low level of soil N as discussed above.

There was little or no response in 100-kernel weight to 100N at 0 and 100P, but some response to 100N with 200P (Figure 4.4). There was a marked response to 200N over 100N at all levels of P. Phosphorous is

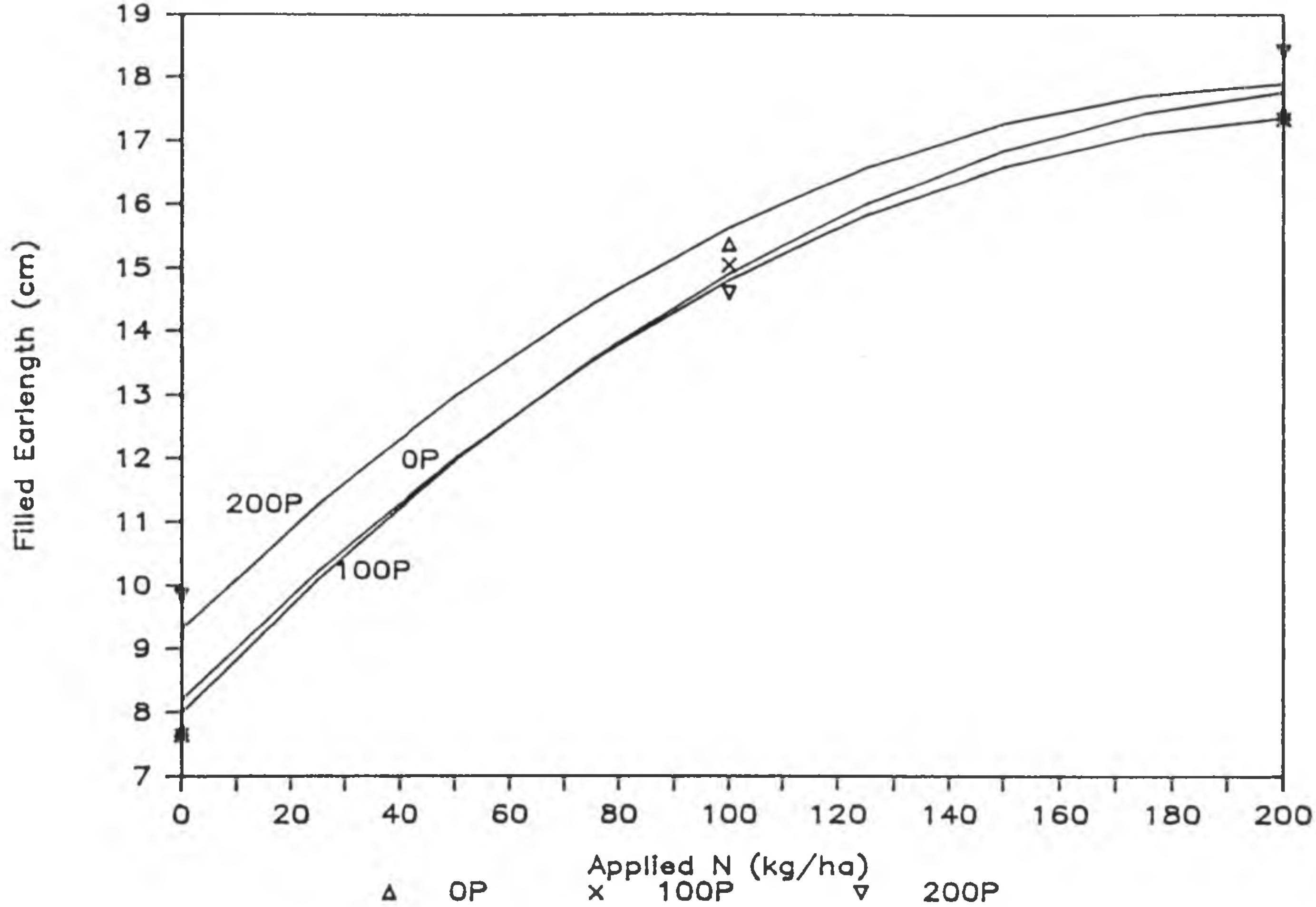


Figure 4.3. The effect of applied N and P on filled earlength of maize. (R^2 = 0.94. Refer to Appendix B for regression coefficients.)

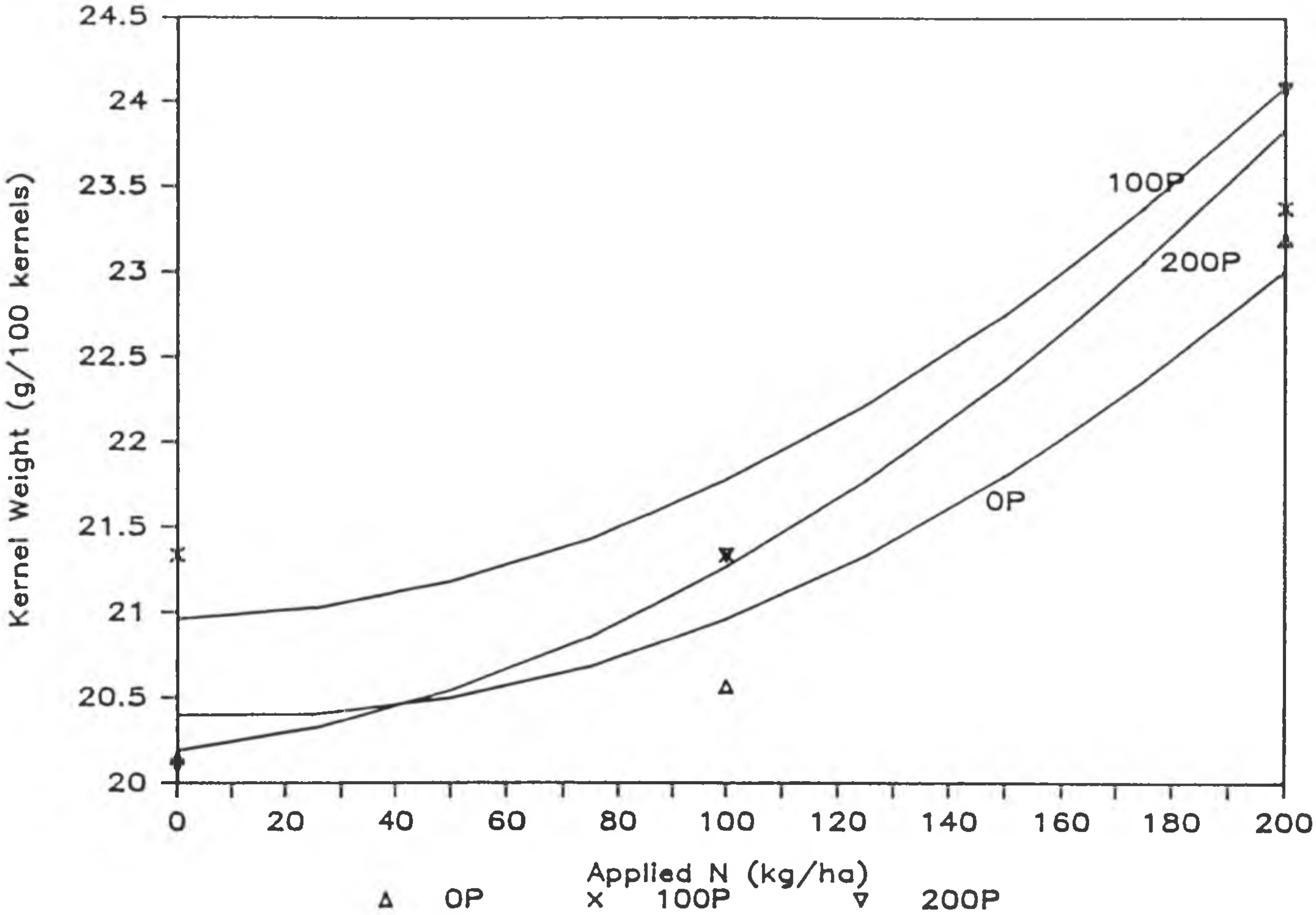


Figure 4.4. The effect of applied N and P on 100-kernel weight of maize. (R^2 = 0.50. Refer to Appendix B for regression coefficients.)

Table 4.2. Average Preplant and Postharvest Soil N Values for Treatments 7, 8 and 9.

	N ($mg\ kg^{-1}$)					
	NH_4		NO_3		Total	
Trt	Preplant	Postharvest	Preplant	Postharvest	Preplant	Postharvest
7	12.57	6.08	4.91	1.08	17.47	7.16
8	16.95	4.83	4.61	1.50	21.57	6.33
9	13.10	3.31	0.00	0.00	13.10	3.31

Table 4.3. Analysis of Ear Leaf N for Treatments 7, 8 and 9.

Treatment	Ear Leaf N (%)
7	1.86
8	1.72
9	1.57

important in seed production (de Geus, 1973) and data from the present experiment indicate that heavier kernels were produced with P as long as N was not seriously limiting (Figure 4.4).

4.1.1.2 Plant Height.

Nitrogen and P were of nearly equal importance in the early growth of maize; height A, measured at 24 days after planting (DAP) had R^2 values of 0.372 and 0.295 for N and P, respectively (Table 4.4). However, at heights B and C, measured at 57 and 119 DAP, respectively, the influence of N became much more important while P became insignificant. The decreasing importance of P in the determination of plant height is well illustrated in Figures 4.5, 4.6 and 4.7. At 24 DAP, the differences in height among the P treatments are large, at any given level of N application (Figure 4.5). These differences were not so large at 57 DAP, but the general trend of height increasing with P is still visible (Figure 4.6). However, at 119 DAP, it is obvious that plant height was not influenced by applied P, especially above 100P. Nevertheless, at all three growth stages, plant height consistently increased with increasing rates of applied N (Figures 4.5, 4.6 and 4.7).

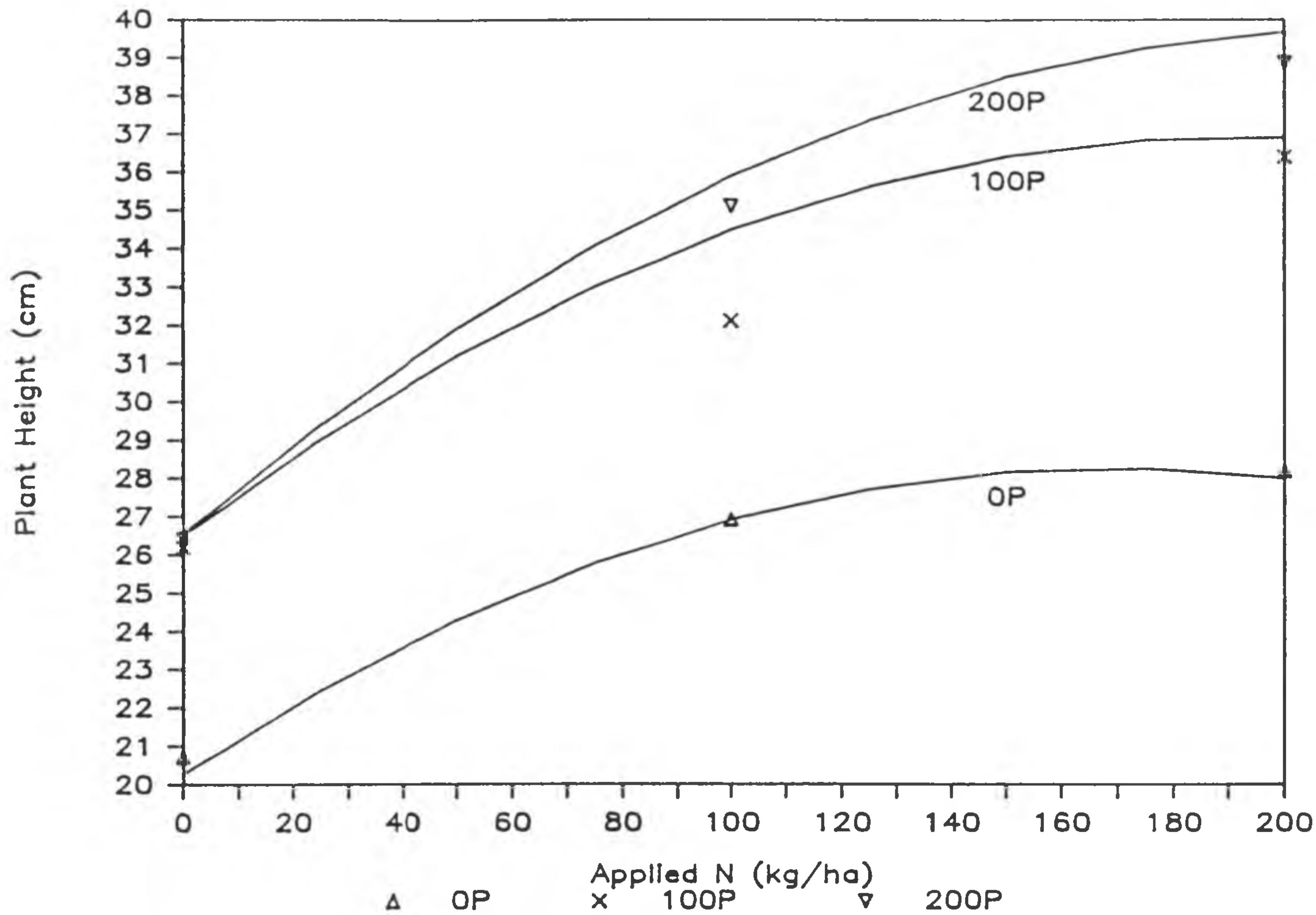


Figure 4.5. The effect of applied N and P on maize plant height at 31 DAP (Height A). (R^2 = 0.66. Refer to Appendix B for regression coefficients.)

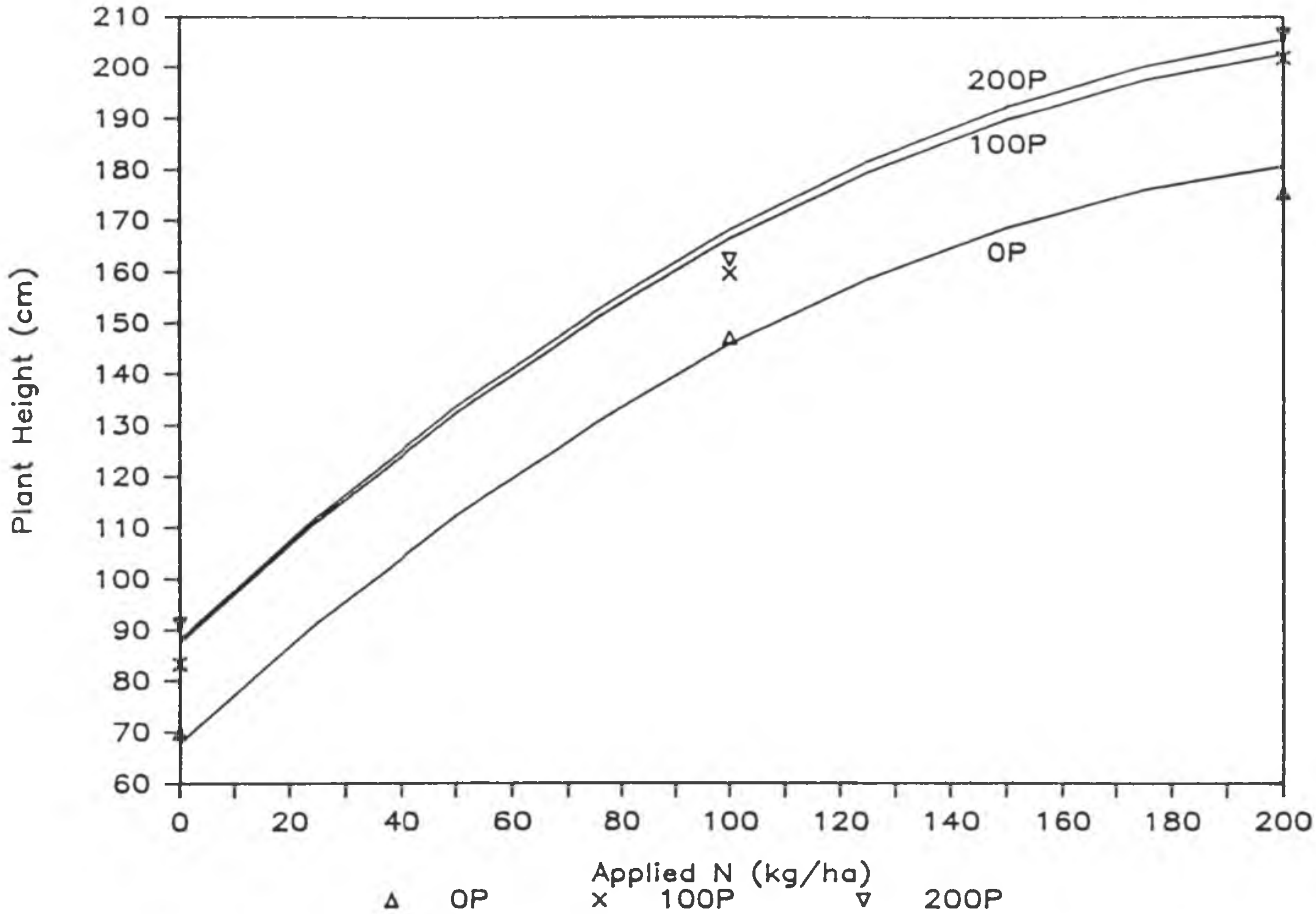


Figure 4.6. The effect of applied N and P on maize plant height at 54 DAP (Height B). (R^2 = 0.93. Refer to Appendix B for regression coefficients.)

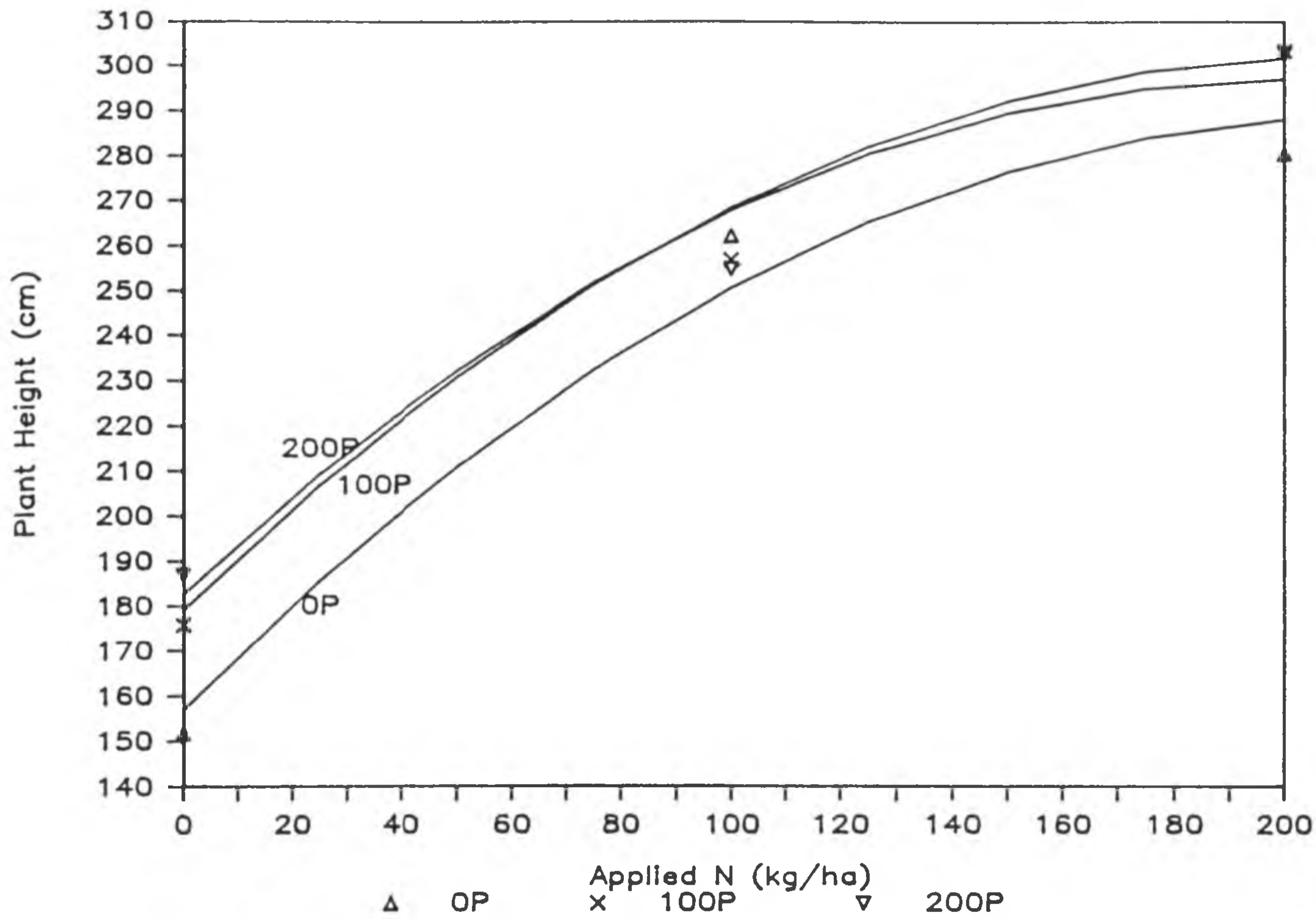


Figure 4.7. The effect of applied N and P on maize plant height at 119 DAP (Height C). (R^2 = 0.91. Refer to Appendix B for regression coefficients.)

Table 4.4. R Square Values for Maize Plant Height for three Regression Models.

Quadratic Model	R Square Values		
	Height A	Height B	Height C
N	0.372	0.891	0.887
P	0.295	0.049	0.033
NP	0.664	0.931	0.911

Pleshkov (1958) reported that the availability of high doses of P to young plants enhances the rate of N metabolism. This may explain the results of this experiment which show that P is of importance only soon after planting, while the importance of N carries over for much of the maize-growing period. However, it should be realized that, unlike P which was applied only before planting, N was applied thrice: once before planting and twice during the maize growing period. This may have contributed to the more extended period of influence of N.

Arnon (1974) also reported that P is of great importance during the early stages of maize growth. Young maize plants have limited root systems that are not capable of extracting sufficient P from the soil, and, furthermore, they cannot compete effectively with soil microorganism for available soil P.

Even though the R^2 values indicate that the N model, without any P, provides a good description of the growth of maize (Table 4.4), the fact that the NP model had a significantly lower MSE (Appendix A2) indicates that P did influence maize height to some extent.

4.1.1.3 Growth (Daily Increase) in Plant Height.

The influence of N was always greater than that of P for all the 6 growth rates (growth per day) (Table 4.5). The R^2 values for growth rates A, B and C are the same as those of plant heights A, B, and C, respectively, as expected. The explanation tendered above for plant heights are also applicable to growth rates. Growth rates AB and AC had similar R^2 values: very high for N and very low for P. However, for growth rate BC, the R^2 values for both N and P are very low. It has already been established above that P increased plant height and plant growth predominantly in the initial growth stages while N increased plant height throughout most of the crop. However, after tasseling (height C), little additional growth occurred, therefore neither N nor P had any effect on growth rate BC since the maize crop was maturing and height was limited by genetic factors.

Table 4.5. R Square Values for Maize Growth (Increase in Plant Height) for three Regression Models.

Quadratic Model	R Square Values		
	AB	AC	BC
N	0.896	0.885	0.097
P	0.024	0.016	0.024
NP	0.914	0.898	0.176

The fact that the N and NP models for growth rates AB, AC, and BC were not significantly different (Appendix 1B) confirms the conclusion that P did not have much influence on growth rates measured after 24 DAP.

4.1.1.4. Biomass.

In this section, biomasses A and B will be discussed first, then biomass C (ears and stover), and finally ear leaf weights. For biomass A, N and P effects were similar (Table 4.6). In fact, P appears to be somewhat more important than N at this stage. However, in the later stages, biomasses B and C, nitrogen is definitely of far greater importance than P. This pattern was also observed for plant height and the growth, per day, in plant height, where N and P were of similar importance in the beginning of the crop then N became more important while P became less important. The pattern, in both instances, may be explained in terms of the limited root system of maize in the early stages of growth which make the plant dependent on the supply of readily available P. Thus, although N had the largest effect on biomass, P also contributed to the determination of plant height (Table 4.6; Appendix A4).

Table 4.6. R Square Values for Maize Biomass and Ear Leaf Weights for three Regression Models.

Quadratic Model	R Square Values				
	A	B	C(Ears)	C(Stover)	Ear Leaves
N	0.203	0.855	0.898	0.810	0.912
P	0.298	0.132	0.306	0.397	0.013
NP	0.578	0.949	0.936	0.893	0.921

In all biomass determinations, biomass increased with increasing rates of applied N (Figures 4.8, 4.9, 4.10, 4.11 and 4.12). Initially, biomass increased rapidly with increasing N but it increased more gradually as N increased above 100N when growth factors other than N became limiting. Applied P was one of the factors that limited biomass production at high N levels at 31 and 73 DAP, because biomass increased markedly with increasing levels of applied P (Figures 4.8 and 4.9). This is reflected in the high R^2 values for the NP model in both cases. With sorghum, Reneau et al. (1983) observed that P increased forage yields for each of the three years of their study which was conducted on a Rhodic Paleudult in Virginia, USA.

For biomass C, it appeared that N was a little more important for ears (R^2=0.898) than for stover (R^2=0.810). This tends to agree with the findings of Barber and Olson (1968) which showed that approximately two-thirds of the total N uptake of maize was eventually accumulated in the grain at maturity.

Furthermore, N was also more important than P in ear leaf weight. There was no definite response by ear leaf weight to applied P but, irrespective of the rate of P applied, ear leaf weight increased with the level of applied N (Figure 4.12). Analysis of the MSE values show that the N and NP models are not significantly different which confirms the conclusion that the increase in ear leaf weight was due mainly to N. This is not surprising as it is known that N plays the leading role in increasing maize production mainly because it enhances vegetative growth (de Geus, 1973).

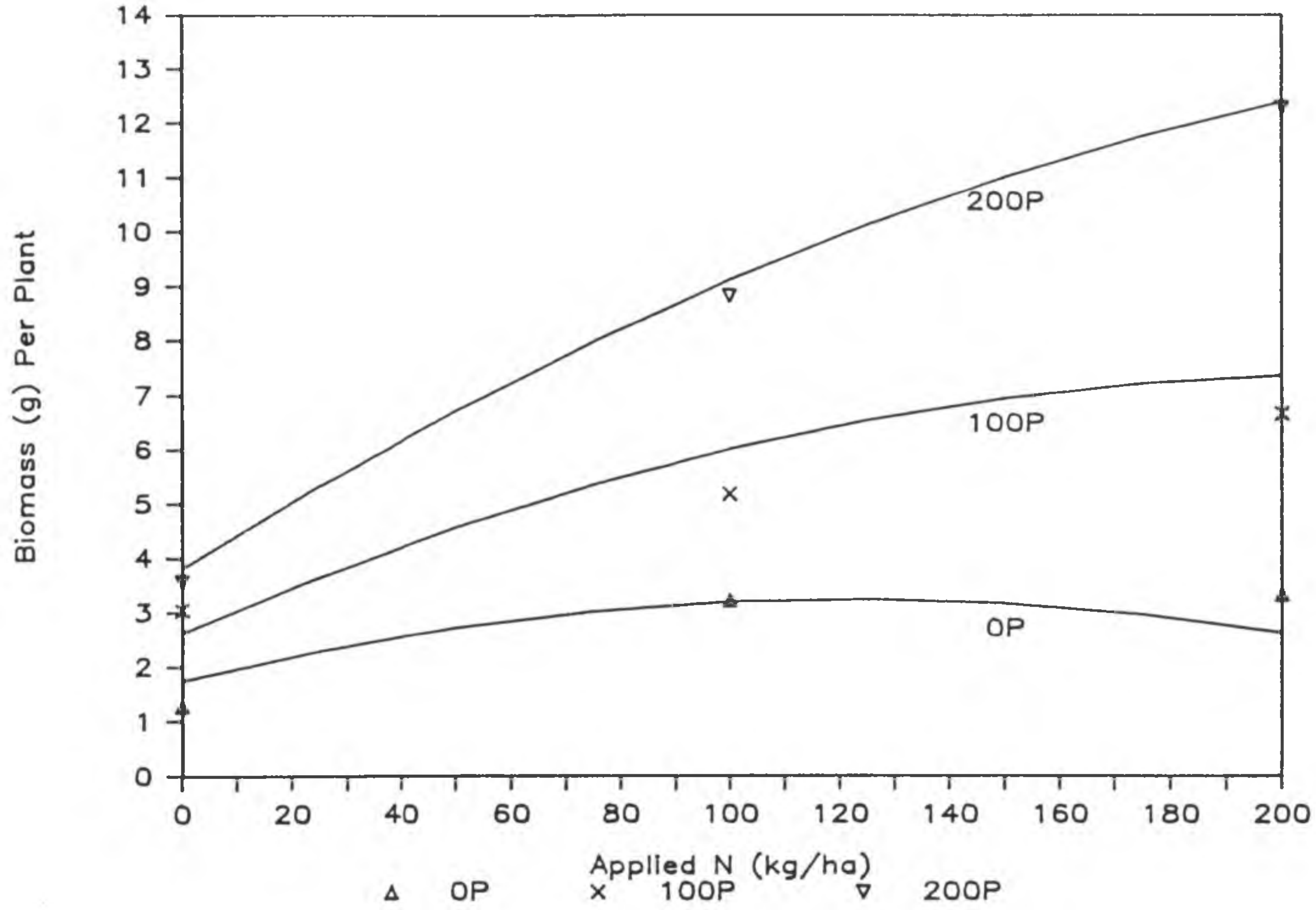


Figure 4.8. The effect of applied N and P on maize biomass at 31 DAP (Biomass A). (R^2 = 0.58. Refer to Appendix B for regression coefficients.)

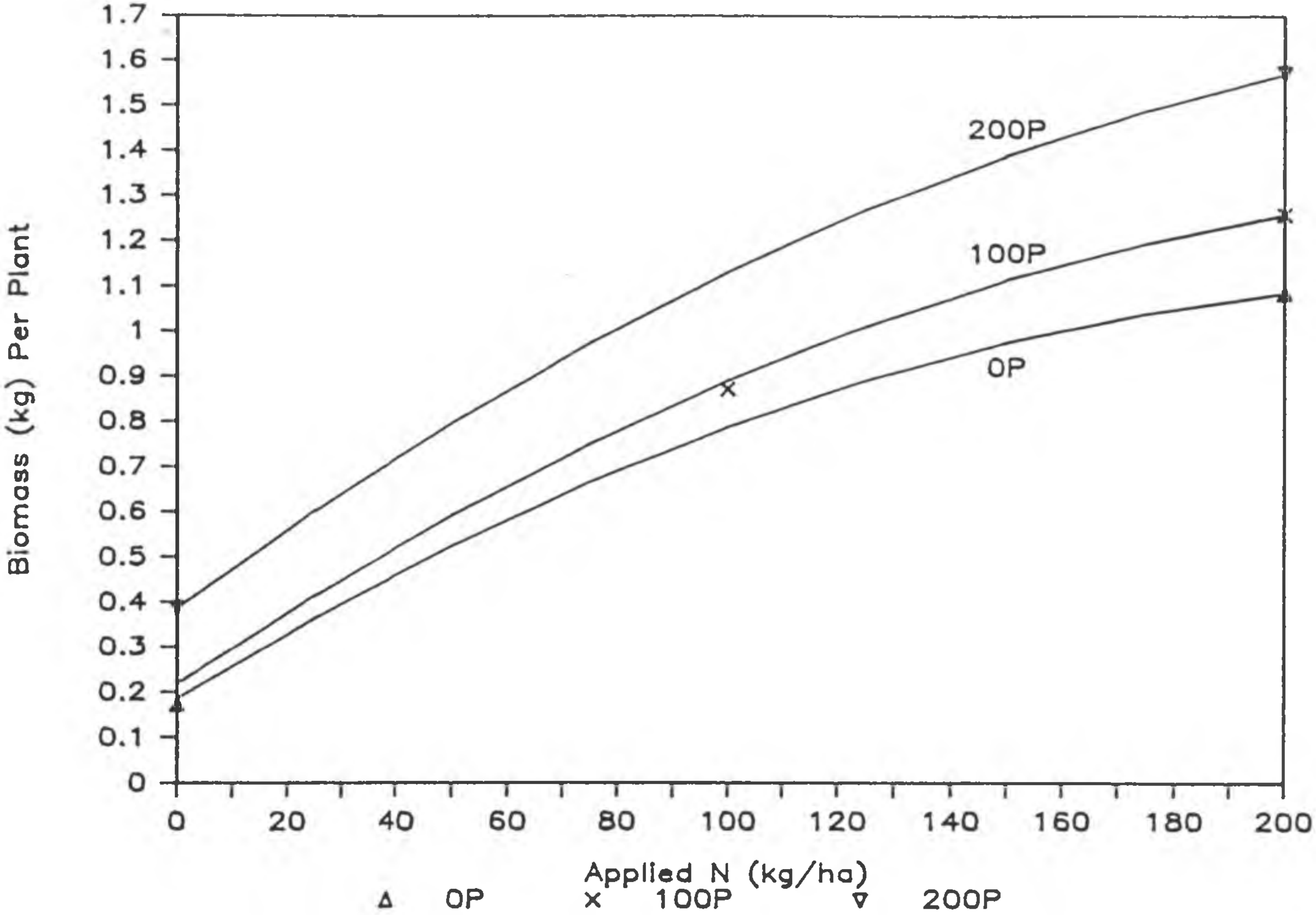


Figure 4.9. The effect of applied N and P on maize biomass at 73 DAP (Biomass B). (R^2 = 0.95. Refer to Appendix B for regression coefficients.)

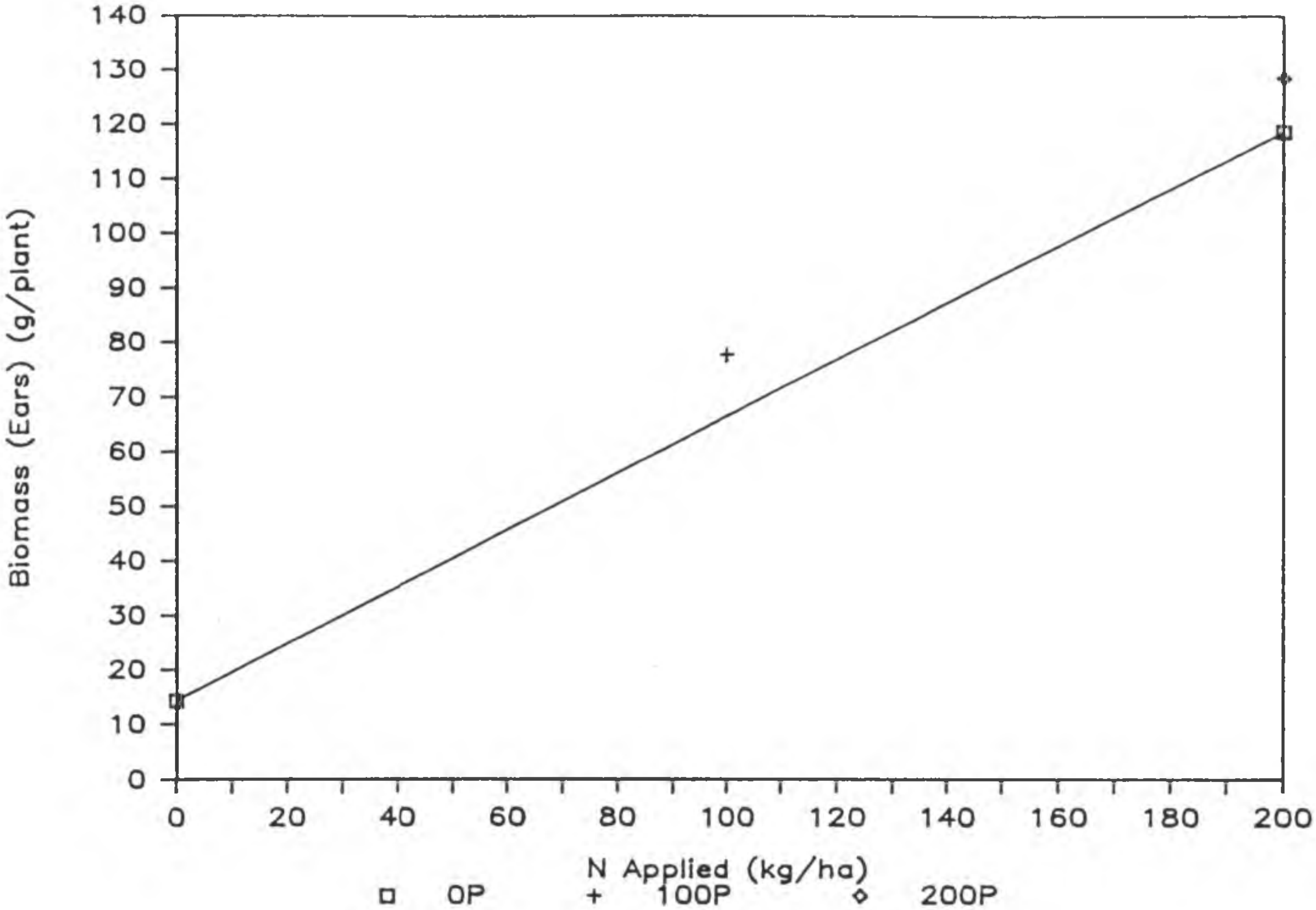


Figure 4.10. The effect of applied N and P on biomass of maize ears at the dough stage (Biomass C, ears). (R^2 = 0.94.)

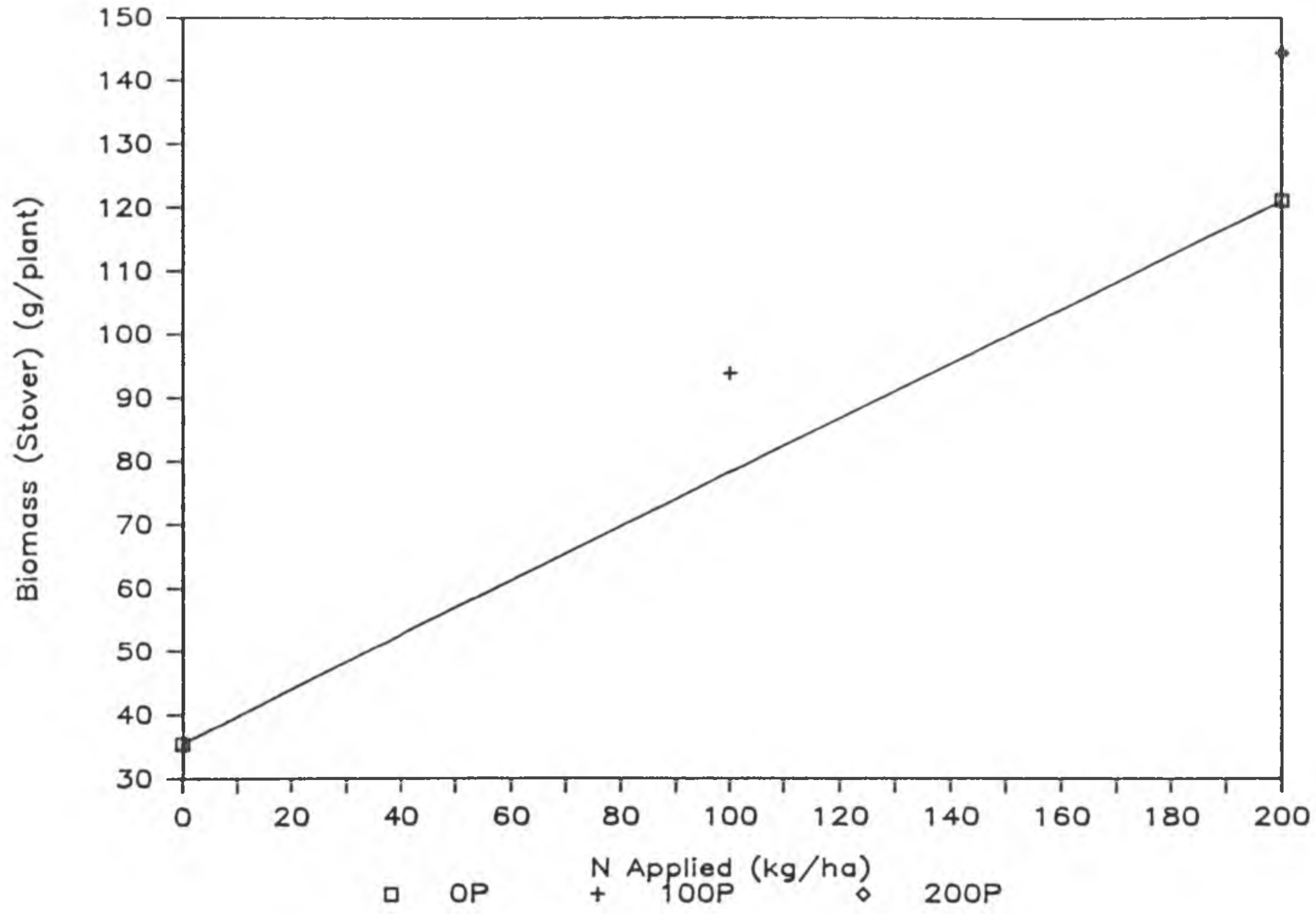


Figure 4.11. The effect of applied N and P on biomass of maize stover at the dough stage (Biomass C, stover). (R^2 = 0.89.)

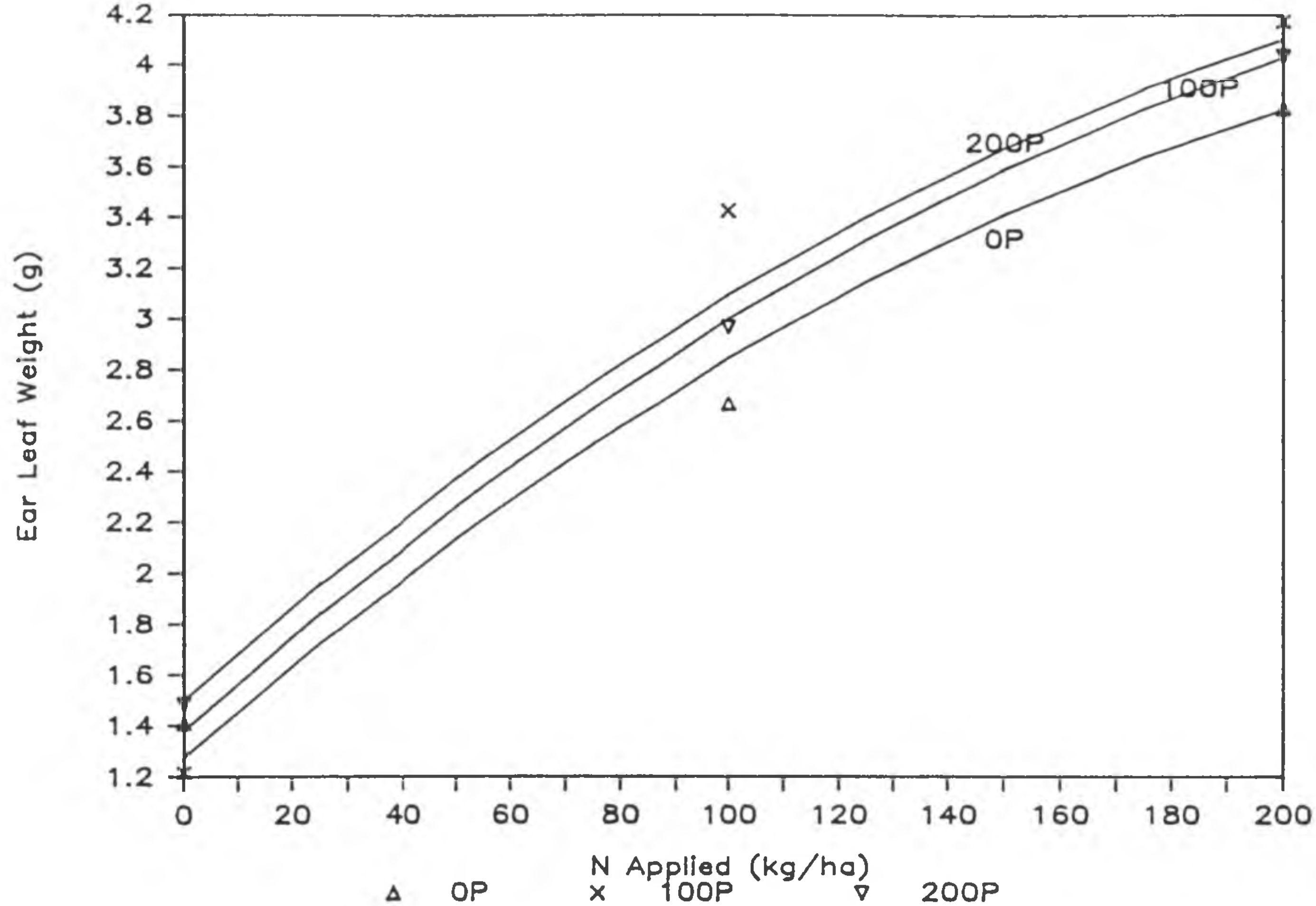


Figure 4.12. The effect of applied N and P on maize ear leaf weight. (R^2 = 0.94. Refer to Appendix B for regression coefficients.)

4.1.1.5. Biomass Growth Rates.

Phosphorous appeared to have greater influence on the daily increase in total above-ground biomass (growth rate) from planting to 31DAP (Rate A); while N was more important for growth rates from planting to 73DAP (Rate B), and from 31DAP to 73DAP (Rate AB), (Table 4.7). For all three growth rates, the NP model provided a significantly better fit of the experimental data than the N or P model alone (Table 4.7, Appendix A5). This indicates that even though N had a greater influence on growth rates B and AB, phosphorous also had an impact on these variables.

Table 4.7. R Square Values for Maize Growth in Biomass (Increase in Biomass) for three Regression Models.

Quadratic Model	R Square Values A	B	AB
N	0.203	0.855	0.854
P	0.298	0.132	0.137
NP	0.578	0.949	0.960

4.1.1.6. Phenological Development.

In this section the phenological variables to be discussed include days to 50% tasselling (TAS), days to 50% silking (SIL), the difference between the two dates (SIL-TAS), crop greenness (GRN), crop brownness (BRN), number of dead leaves (DL) and days to physiological maturity (DPM).

Table 4.8. R Square Values for Maize Phenological Variables for three Regression Models.

Quadratic Model	R Square Values						
	TAS	SIL	SIL-TAS	GRN	BRN	DL	DPM
N	0.749	0.899	0.820	0.848	0.404	0.456	0.576
P	0.116	0.059	0.017	0.004	0.254	0.055	0.028
NP	0.866	0.946	0.831	0.850	0.670	0.517	0.604

Days to 50% Tasselling: The number of days required for maize to reach 50% tasselling, was influenced much more by N than P (Table 4.8). Days to 50% tasseling decreased with increased applied N; and the rate of this decrease was higher when less than 100N was applied (Figure 4.13). When 100N or more was added, the rate of decrease in days to 50% tasseling was lower, presumably, because the genetic limit of the maize plant was being approached.

The effect of fertilization on days to booting and full bloom in sorghum have been discussed by Brawand and Hossner (1976) and by other authors. Research published by Lane and Walker (1961) indicated that grain sorghum check plots required about one week longer for attainment of booting and full bloom than fertilized sorghum at the Texas Agricultural Experiment Station. Observations by Brawand et al. (1971) in the Blackland Prairie Soils of Texas show average planting to half bloom periods of, 94 days for continuous unfertilized grain sorghum, 90 days for unfertilized rotation grain sorghum, and 78 days for the most highly fertilized rotation sorghum.

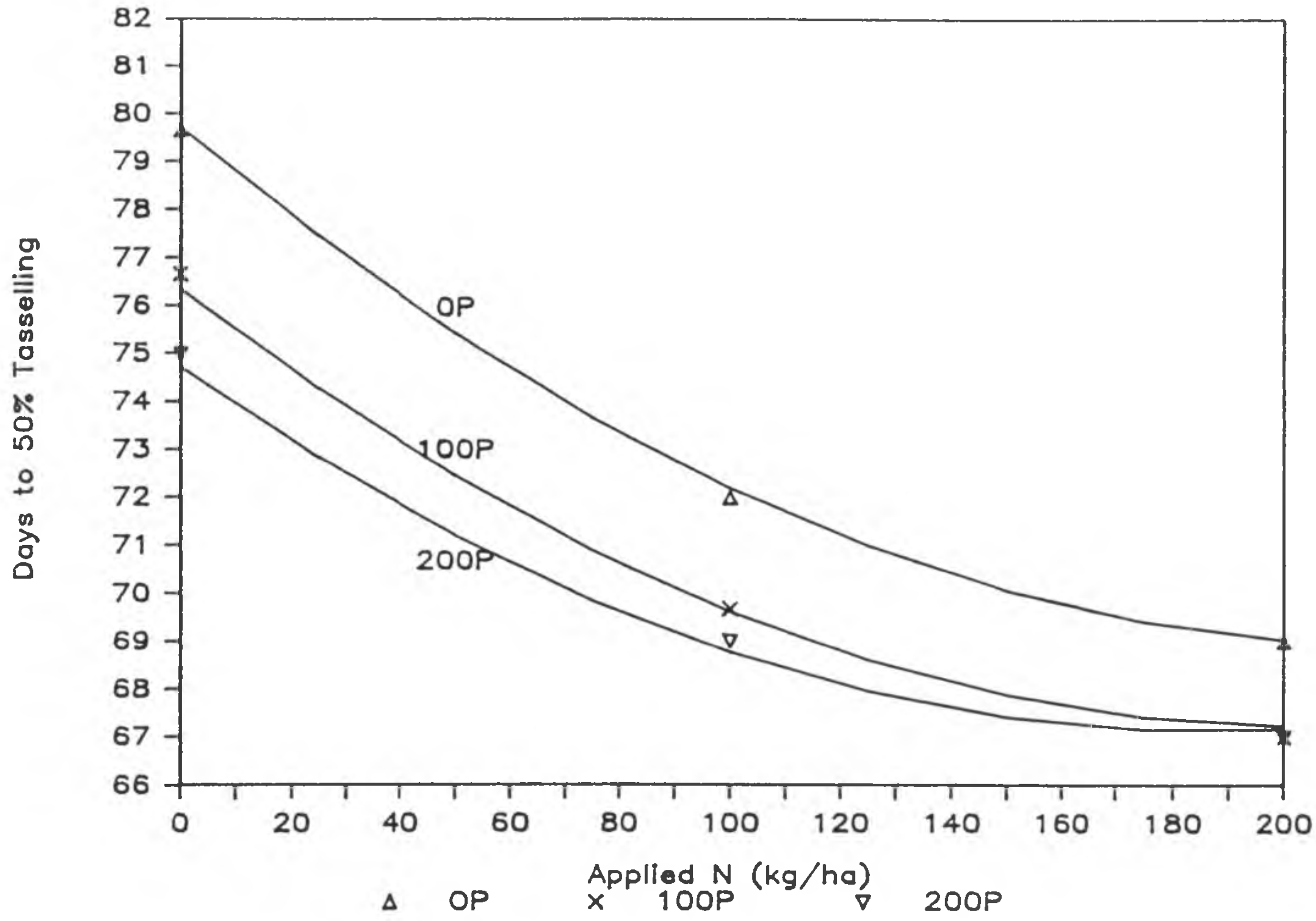


Figure 4.13. The effect of applied N and P on the number of days to 50% tasselling of maize. (R^2 = 0.87. Refer to Appendix B for regression coefficients.)

The fact that the NP model provided a significantly better fit for the experimental data than the N model (Appendix A6) is an indication that P had an effect on days to 50% tasseling. Days to tasselling were consistently less for the higher rates of applied P at all levels of applied N (Figure 13).

Days to 50% Silking: Nitrogen was also much more important than P in determining the number of days to 50% silking (Table 4.8). This is evident from Figure 4.14 where days to 50% silking decreased with increasing levels of both applied N and P. With increasing rates of applied N to 100N, days to 50% silking decreased very rapidly. When more than 100 kg N/ha was added, the decrease was not so rapid as genetic and other factors became limiting. Figure 4.14 also shows that days to 50% silking decreased as the rate of applied P increased. This decrease was subtle and not statistically significant, but the decrease was observed for all N levels. The NP model also had a larger R^2 than the N model and a significantly smaller MSE (Appendix A6). Therefore, there is good evidence that P had an important role in the determination of days to 50% silking.

Period between tasselling and silking: According to Table 4.8, the period between tasselling and silking was determined more by N than P. This is supported graphically by Figure 4.15 in which the period between tasselling and silking is seen to decrease rapidly as rate of applied N increases to 100N. Above 100N, the period between tasselling and silking continued to decrease but at a slower rate. It is apparent that P is also a limiting factor because, below 100N, the period

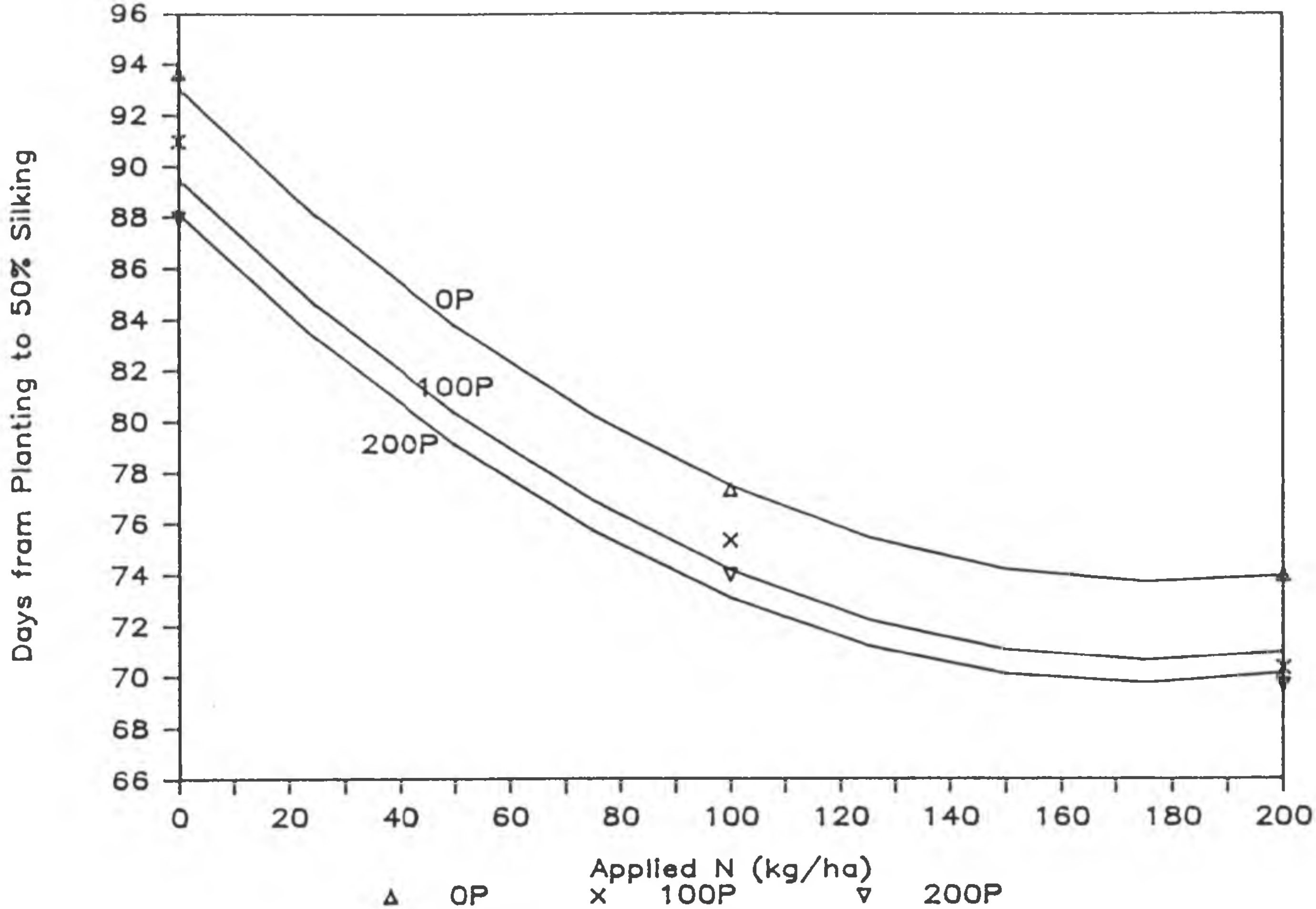


Figure 4.14. The effect of applied N and P on the number of days to 50% silking of maize. ($R^2 = 0.95$. Refer to Appendix B for regression coefficients.)

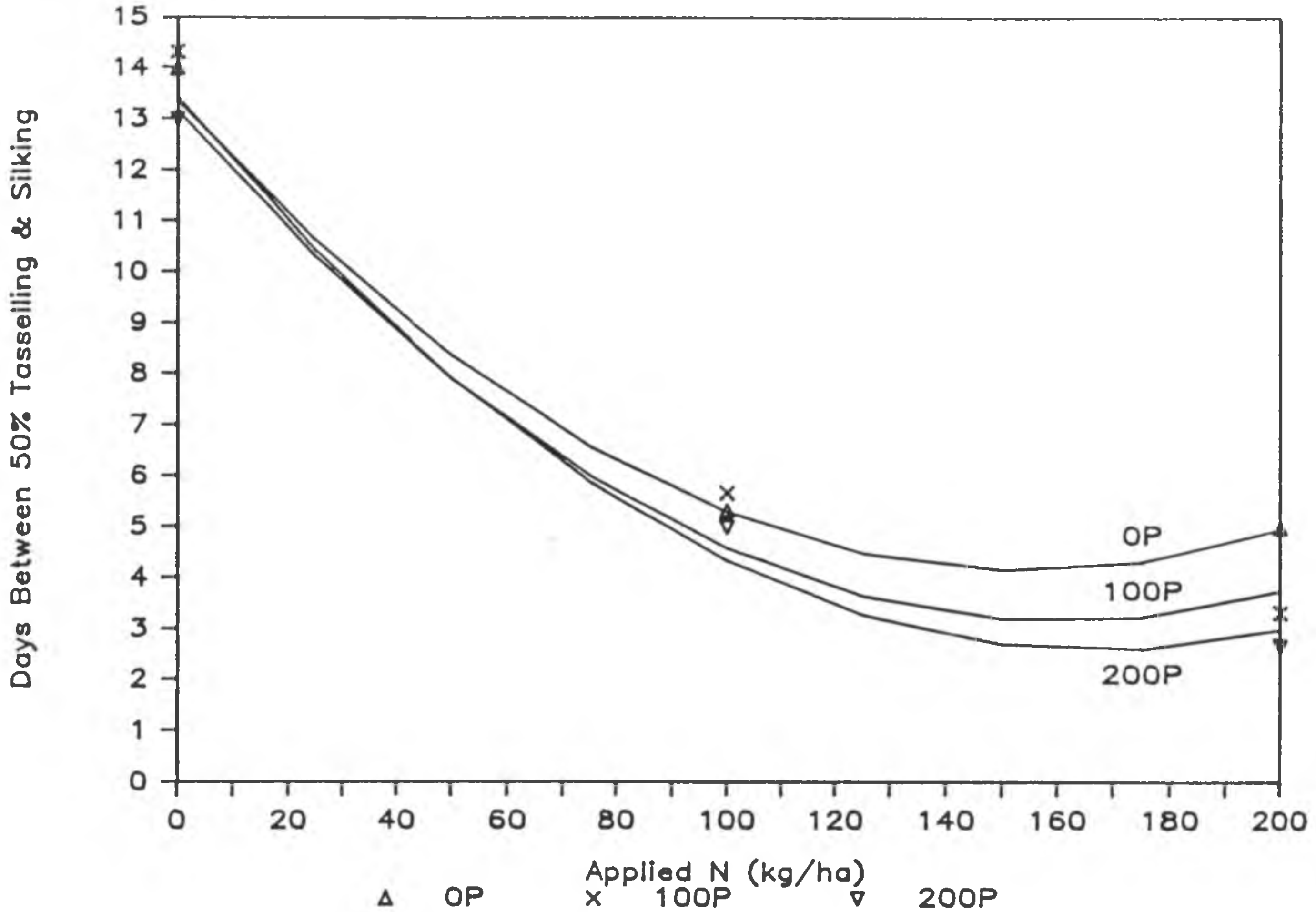


Figure 4.15. The effect of applied N and P on the number of days between tasselling and silking of maize. (R^2 = 0.83. Refer to Appendix B for regression coefficients.)

between tasselling and silking was lower for 200P than for 0 or 100P at all levels of applied N. However, above 100N, the period between tasselling and silking remained constant with 0P, but continued to decrease with 100 and 200P.

It is apparent that days to tasselling and silking can vary by as much as 14 days when N is not applied, and that 200P helps to reduce this somewhat. The smallest difference, 4 to 5 days, occurred at the highest rate of N and P. Again, the lack of applied P caused the difference to be greater (7 to 8 days). Thus N and P nutrition can have a marked effect on days to tasselling and silking.

<u>Crop Greenness</u>: Greenness of the maize crop is an important response variable because it reflects the photosynthetic ability of the plant which, in turn, has an important influence on grain and stover yields. From Table 4.8 and Figure 4.16 it is obvious that N was the major factor affecting crop greenness at 95 DAP, while P had essentially no effect on this. Crop greenness increased with increasing rates of N application. The rate of increase in greenness was slightly higher when N was applied up to 100N than from 100 to 200N. At the high N rate it is possible that P, genetic and, other factors, became limiting. A rate of 200P appeared to produce greener plants than 0 or 100P with 200N (Figure 4.16).

<u>Crop Brownness</u>: The degree of browning and necrosis of leaves of maize at 130 DAP is a reflection of plant maturity. Plants receiving the highest amounts of N and P generally had more brown leaves than those receiving smaller amounts of N and P, and were also those that

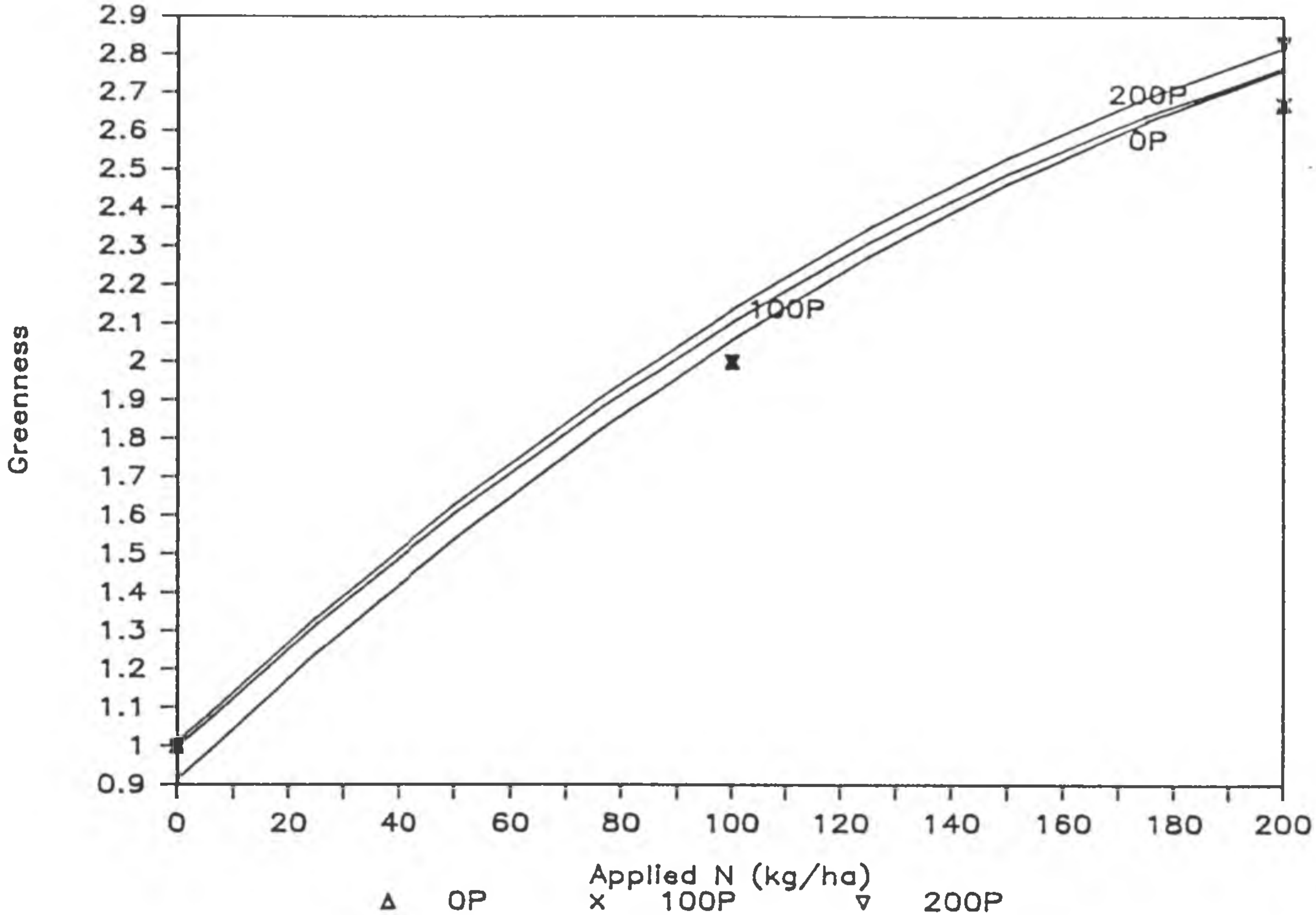


Figure 4.16. The effect of applied N and P on the greenness of maize at 95 DAP. (R^2 = 0.85. Refer to Appendix B for regression coefficients.)

produced the highest yields. Both N and P influenced maturity as indicated by the highest R^2 for the NP model (Table 4.8) and the curve in Figure 4.17. Plants in the high N treatments grew more rapidly, reached the tasselling and silking stages earlier, and matured earlier. Applied P also affected brownness and plants receiving 0 or 100P had greener (less brown) leaves than those receiving 200P at all N levels which reflects the delayed maturity resulting from low P. Leaf necrosis occurs as nutrients, particularly N, are translocated to the grain from the vegetative tissues while others, including P, are left behind in the non-grain tissues. As such, necrosis may be due to N depletion and P accumulation in the vegetative parts of the maize plant.

Crop brownness intensified with increasing rates of applied N up to 100N (Figure 4.17). Above 100N, crop brownness tended to level off; however, for all levels of applied N, brownness increased with P applied.

<u>Number of dead leaves</u>: The photosynthetic efficiency of the maize plant can be increased by ensuring that the maximum number of leaves is photosynthetically active at any one time. Therefore, information was collected on the effects of treatment variables on the number of photosynthetically inactive leaves per plant. Applied N played an important role in the determination of the number of dead leaves per plant at 90 DAP while P effects were not significant (Table 4.8). The number of dead leaves per plant decreased with increasing rates of applied N; and the rate of this decrease was high when N rate was 100N

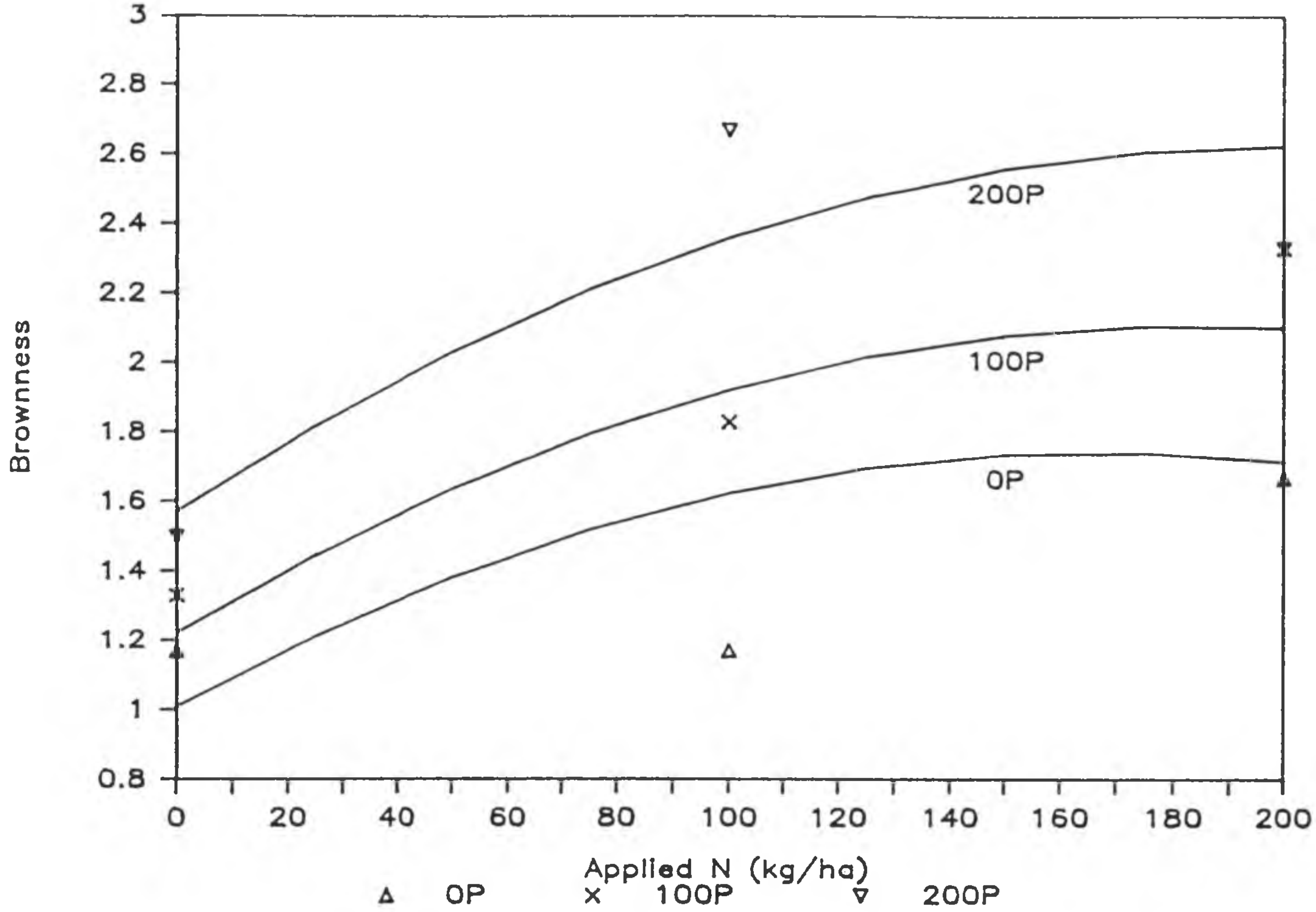


Figure 4.17. The effect of applied N and P on brownness of maize at 130 DAP. (R^2 = 0.67. Refer to Appendix B for regression coefficients.)

or lower (Figure 4.18). Above 100N, the number of dead leaves per plant tended to level off as genetic and other factors became limiting. The MSE values for the N and NP models are not significantly different, which agrees with both the R^2 values of Table 6 and the graph of Figure 4.18 which indicate that there is no consistent relationship between the number of dead leaves per plant at 90 DAP and the rate of P applied.

Days to physiological maturity: The number of days required by maize to reach physiological maturity is of importance to researchers as well as farmers for a number of reasons including the fact that the duration of this period is an important factor in determining the economics of crop production. Therefore, data were obtained on the days required to reach physiological maturity to determine the effects of N and P on this variable.

The number of days required by maize to reach physiological maturity was determined largely by the rate of N applied (Table 4.8; Figure 4.19). The decrease in growing period with increased N was nearly linear from 0 to 200N and did not display the levelling off above 100N as was observed for many of the other response variables pertaining to phenological development.

The N and NP models are not significantly different (Appendix A6) indicating that P had no consistent effect on days to maturity. However, days to maturity are lower for higher rates of applied P at the highest level of applied N (Figure 4.19).

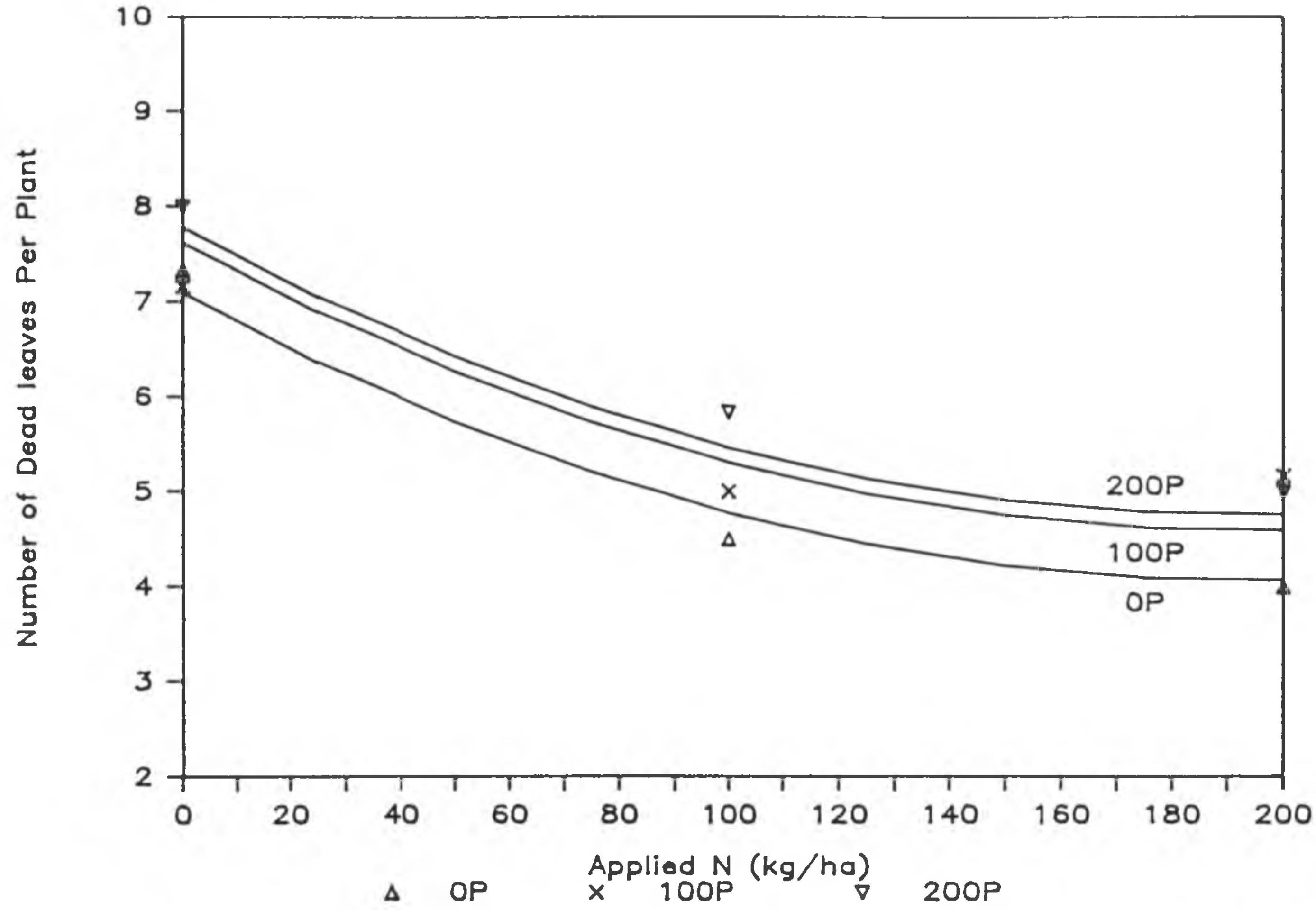


Figure 4.18. The effect of applied N and P on the number of dead leaves on maize at 90 DAP. (R^2 = 0.52. Refer to Appendix B for regression coefficients.)

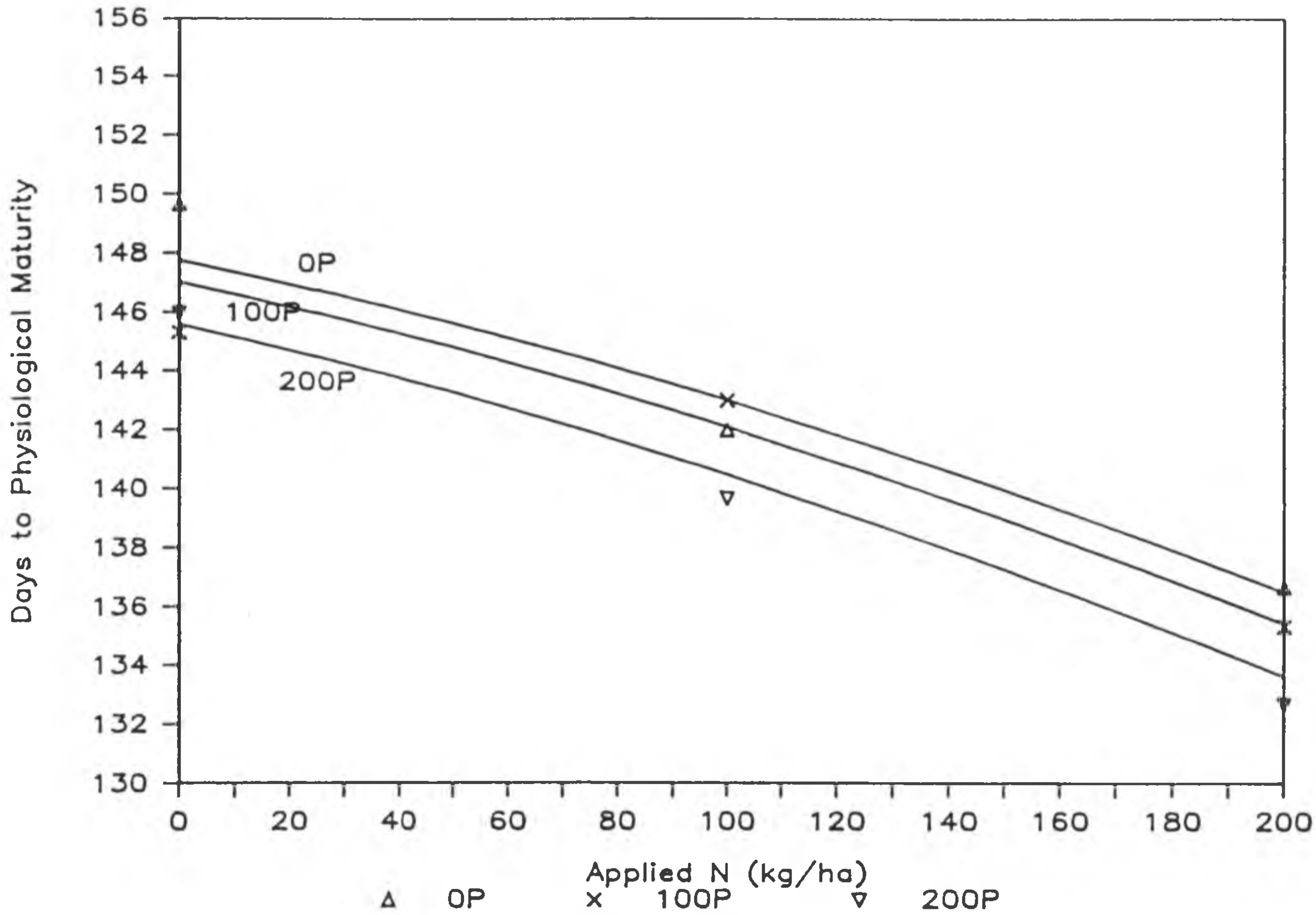


Figure 4.19. The effect of applied N and P on the number of days to physiological maturity of maize. (R^2 = 0.60. Refer to Appendix B for regression coefficients.)

4.1.1.7. Ear Leaf Analysis.

The rates of applied N played an important role in the determination of the concentrations of ear leaf N, Mn, S, Ca and Fe while the rates of applied P were important in determining the concentration of ear leaf Cl (Table 4.9). However, since R^2 values for the NP models for Mg, Si, K, Al, P, Zn and Cu were well below 0.5, it is assumed that neither N nor P rates had significant effects on the concentrations of these 7 elements (Table 4.9) which will not be discussed, with the exception of P which is one of the major treatment variables in this experiment.

The experimental means and ranges for N, P, Ca, S, Cl, Fe and Mn are shown in Table 4.10. Comparisons with published nutrient sufficiency ranges for the ear leaf of maize at silking (Table 4.11) reveal that the experimental average as well as the maximum values for N, P, and S in Table 4.10 are low.

Nitrogen: The concentration of ear leaf N increased with increasing rates of applied N at all applied-P levels (Figure 4.20). However, there was no definite relationship between the concentration of ear leaf N and the rate of applied P. Grain yield increased with increasing concentrations of ear leaf N: as the concentration of ear leaf N increased from 1.15% to 1.87%, grain yield increased from 2mt/ha to 11.6mt/ha (Figure 4.21). It is apparent from Figure 4.21 that ear leaf N of 1.75% would be required for a yield of 10Mg ha^{-1}. A comparison of these values with those in the literature indicates that the rates of applied N used in this experiment may not have been

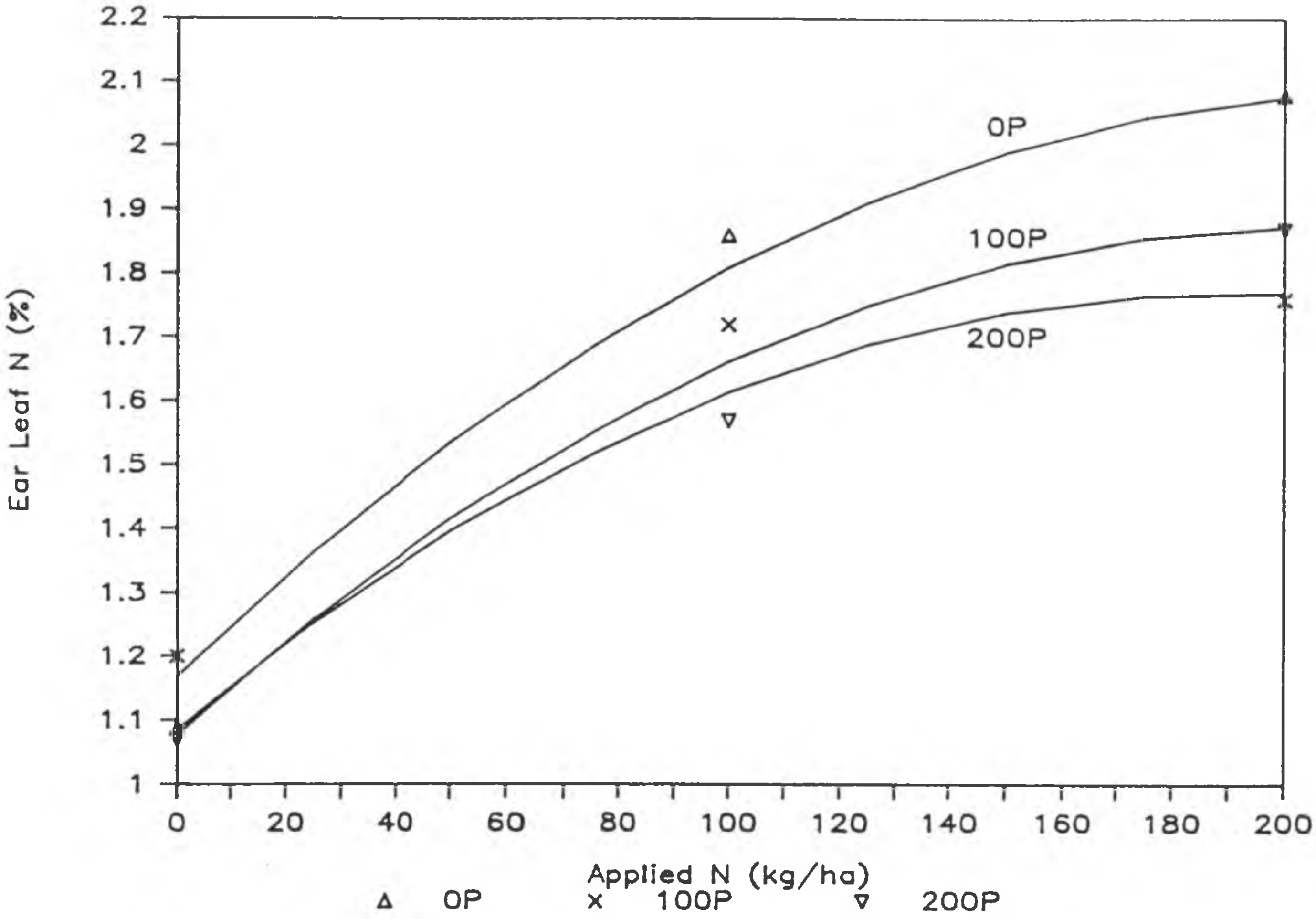


Figure 4.20. The effect of applied N and P on maize ear leaf N.
(R^2 = 0.86. Refer to Appendix B for regression coefficients.)

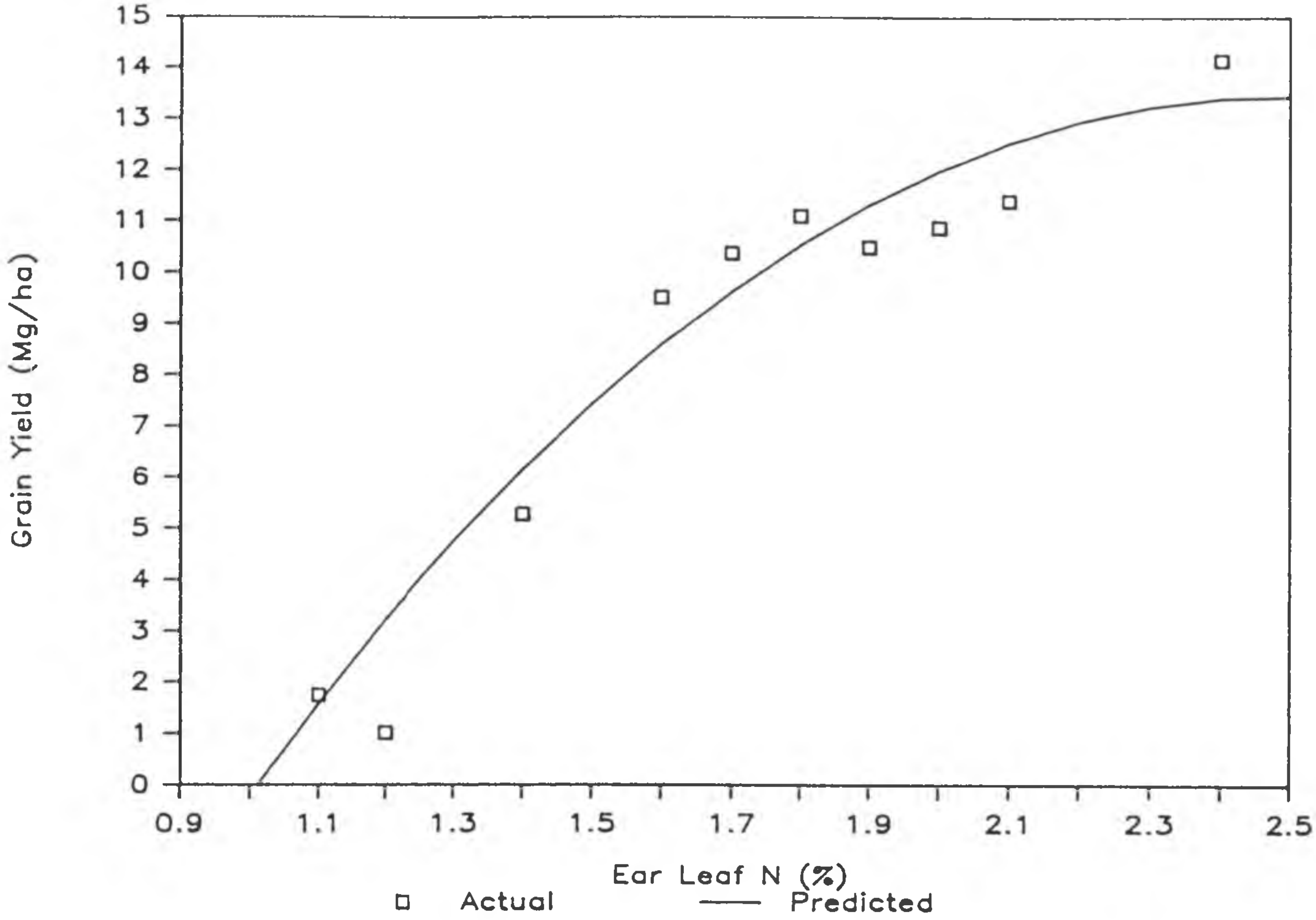


Figure 4.21. The effect of applied N and P on maize ear leaf N and grain yield. (R^2 = 0.81. Refer to Appendix B for regression coefficients.)

Table 4.9. R Square Values for Maize Ear Leaf Nutrients for three Regression Models.

Ear Leaf Element	R Square Values		
	N Model	P Model	NP Model
N	0.805	0.045	0.862
Mn	0.677	0.045	0.746
S	0.616	0.027	0.665
Ca	0.578	0.070	0.685
Fe	0.420	0.199	0.770
Mg	0.191	0.087	0.255
Si	0.172	0.027	0.380
K	0.123	0.078	0.374
Al	0.123	0.027	0.168
P	0.117	0.048	0.218
Cl	0.097	0.397	0.484
Zn	0.086	0.033	0.165
Cu	0.002	0.086	0.091

Table 4.10. Experimental Means and Ranges for Maize Ear Leaf Nutrients.

Element	Mean	Range
	(%)	
N	1.63	1.07-2.38
P	0.17	0.12-0.21
Ca	0.47	0.38-0.62
S	0.08	0.05-0.11
Cl	0.12	0.09-0.20
	($mg\ kg^{-1}$)	
Fe	103	92-142
Mn	111	87-156

Table 4.11. Sufficiency Ranges for Maize Ear Leaf Nutrients at the Silking Stage.

Element	Jones (1967)	Neubert, et al. (1969)
	(%)	
N	2.76-3.50	2.60-4.00
P	0.25-0.40	0.25-0.50
Ca	0.21-1.00	0.21-1.00
S	- - - - -	0.21-0.50
	($mg\ kg^{-1}$)	
Fe	21-250	21-250
Mn	20-150	34-200

sufficient to provide concentrations of ear leaf N that would give maximum yield. However, it must be remembered that values in the literature are based on many varieties and it is possible that the sufficiency values for Pioneer X304-C may differ from those in the literature. Furthermore, soil P was above the adequate level and there was no yield response to added P. Thus it is very unlikely that the ear leaf P level was low.

Phosphorous: The concentration of ear leaf P was not closely related to the levels of either N or P that were applied (Table 4.9). With P application rates of 100 to 200P, the concentration of ear leaf P was inversely related to the level of N applied (Figure 4.22). Furthermore, it is apparent that at low rates of applied N (0 and 100N), the concentration of ear leaf P tended to increase with increasing rates of applied P while at the higher rate of applied N (200N), the concentration of ear leaf P tended to decrease with increasing rates of P. This observation is unlikely to be due to an inhibitory effect of N on P uptake, because the addition of N fertilizers has been shown by many investigators to enhance considerably the utilization of fertilizer P by maize; particularly on soils low in available N (Yakovlev, 1969; Fine, 1955; Miller and Ohlrogge, 1958; Viets et al., 1954; Dormaar and Ketcheson, 1960.). As such, it is assumed that the reduced concentration of ear leaf P with high rates of applied N was due to a dilution effect, i.e., the high N rates produced bigger plants which diluted the concentration of P in the plant's ear leaf.

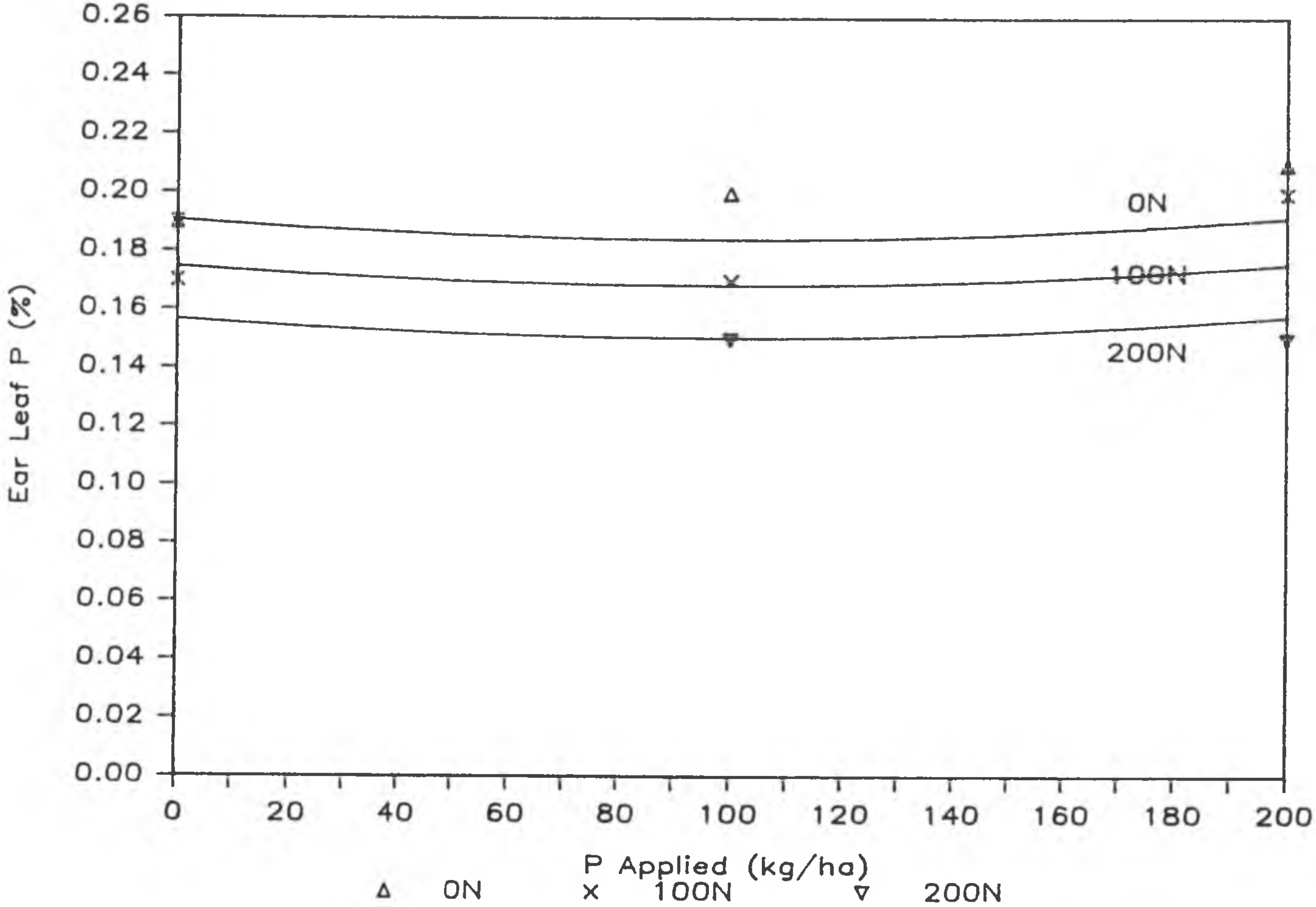


Figure 4.22. The effect of applied N and P on maize ear leaf P.
(R^2 = 0.22. Refer to Appendix B for regression coefficients.)

The R^2 values of Table 4.9 indicate that there was some interaction between the effects of N and P. This is well illustrated in Figure 4.22 which shows that a given increase in applied P (e.g. from 0 to 100P, or from 100 to 200P) resulted in differing increases in ear leaf P, depending on the rate of N applied.

The concentration of ear leaf P and grain yield were found to be linearly and inversely related (Figure 4.23). Grain yield increased from 1 to 11.8 Mg ha^{-1} as the concentration of ear leaf P decreased from 0.190 to 0.160%. Furthermore, Figure 4.23 indicates that an ear leaf P concentration of 0.165% is required to produce a grain yield of 10 Mg ha^{-1}. However, previous studies (Table 4.11) indicate that, at least 0.25% P is required for sufficiency. This does not seem reasonable since there was no response to applied P, and soil P levels were high. Therefore it appears likely that Pioneer X304-C has lower sufficiency levels than those varieties on which the values in the literature are based.

Manganese: The rate of applied N was fairly well correlated with the concentration of ear leaf Mn (Table 4.9, Figure 4.24), which is in agreement with Thompson (1962) who reported that field experiments on a dark-brown clay (pH 5.8) in Southern Rhodesia showed that increasing the N supply increased the Mn content of maize. The concentration of ear leaf Mn tended to decrease slightly when the rate of applied N increased from 0 to 100N with 0 and 200P; however, when the rate of applied N was increased from 100 to 200N, there was a definite increase in the concentration of ear leaf Mn for all P rates.

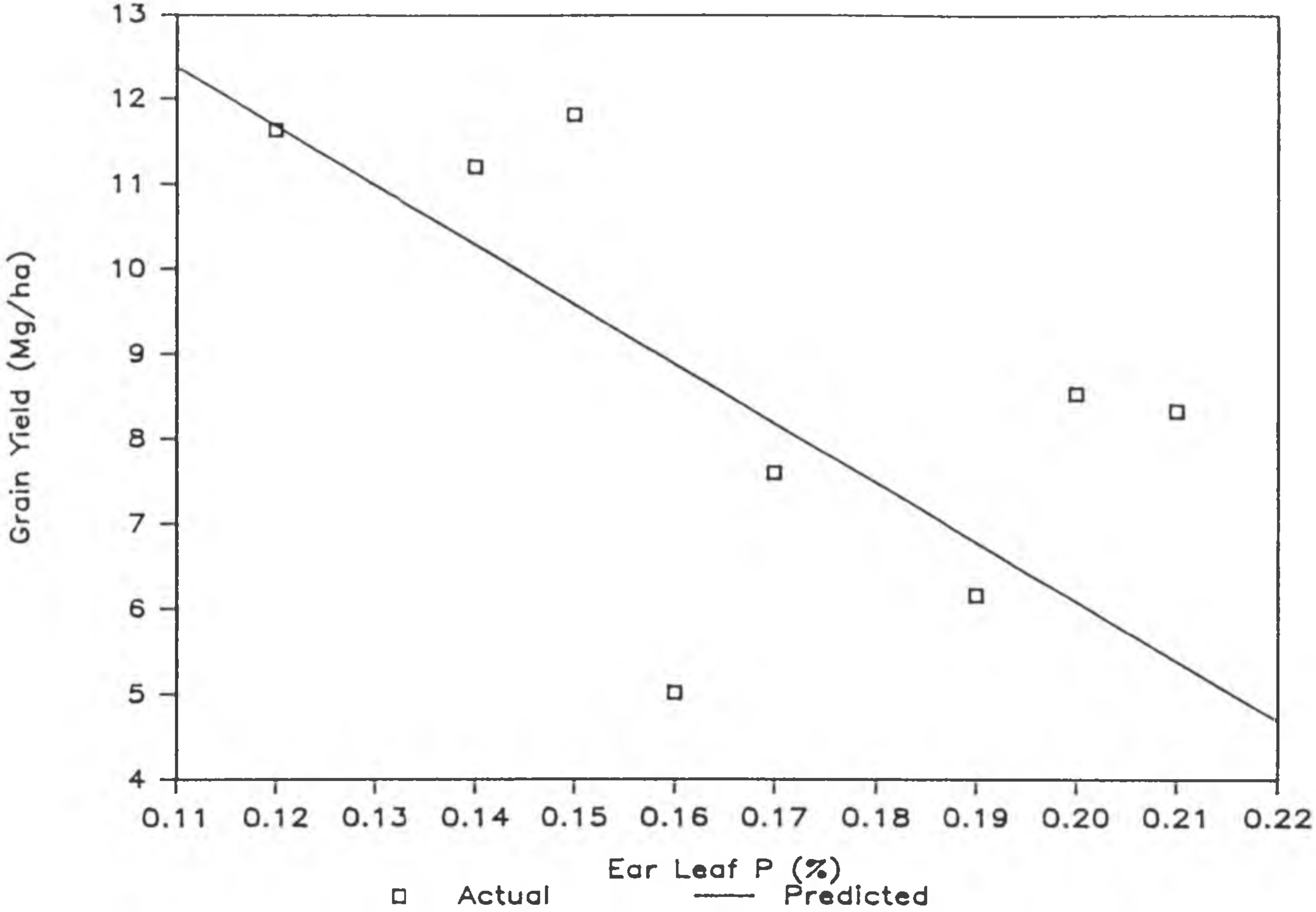


Figure 4.23. The relationship between maize ear leaf P and grain yield. (R^2 = 017.)

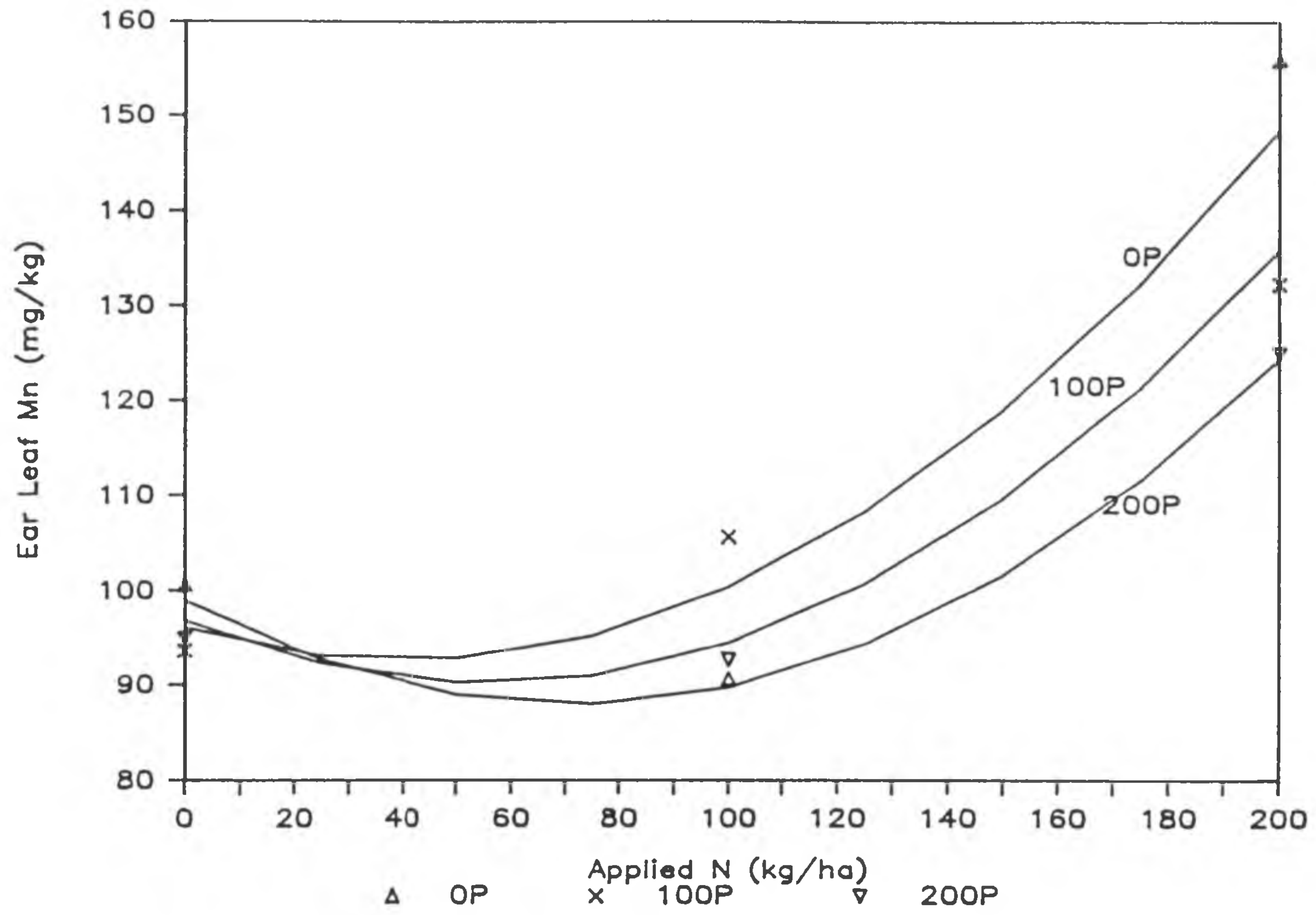


Figure 4.24. The effect of applied N and P on maize ear leaf Mn.
(R^2 = 0.74. Refer to Appendix B for regression coefficients.)

At 200N, the concentration of ear leaf Mn decreased markedly as the rate of applied P was increased. It is unlikely that applied P depressed the uptake of Mn because Bingham (1963) reported that P fertilization increased the availability of Mn. It is assumed that this is caused by a dilution effect because at 200N, ear leaf weight increased with increased rates of applied P above 100P (Figure 4.12), and this increase in ear leaf weight was probably partly responsible for the dilution effect.

The NP model gave an appreciably higher RS value than either the N or the P model alone (Table 4.9), indicating that there was an interaction between the N and P effects. This interaction is illustrated in Figure 4.24 where, a given increase in applied N resulted in variable effects on the concentration of ear leaf Mn, depending on the level of applied P. Concentrations of ear leaf Mn that were measured in this experiment (Table 4.10) were within the sufficiency ranges in the literature (Table 4.11).

Sulfur: The concentration of ear leaf S was well correlated with applied N (Table 4.9, Figure 4.25). The ear leaf concentration of S increased as the rate of applied N increased from 0 to 100N (Figure 4.25). From 100 to 200N, the rate of increase of ear leaf S was lower for 0 and 100P while for 200P ear leaf S actually decreased at 200N. The concentration of ear leaf S was highest with 0P with 200N. Some interactions between the N and P effects were evident as the NP model gave a higher RS value than either the N or the P model alone (Table 4.9). Stewart and Porter (1969) have shown that there is a close

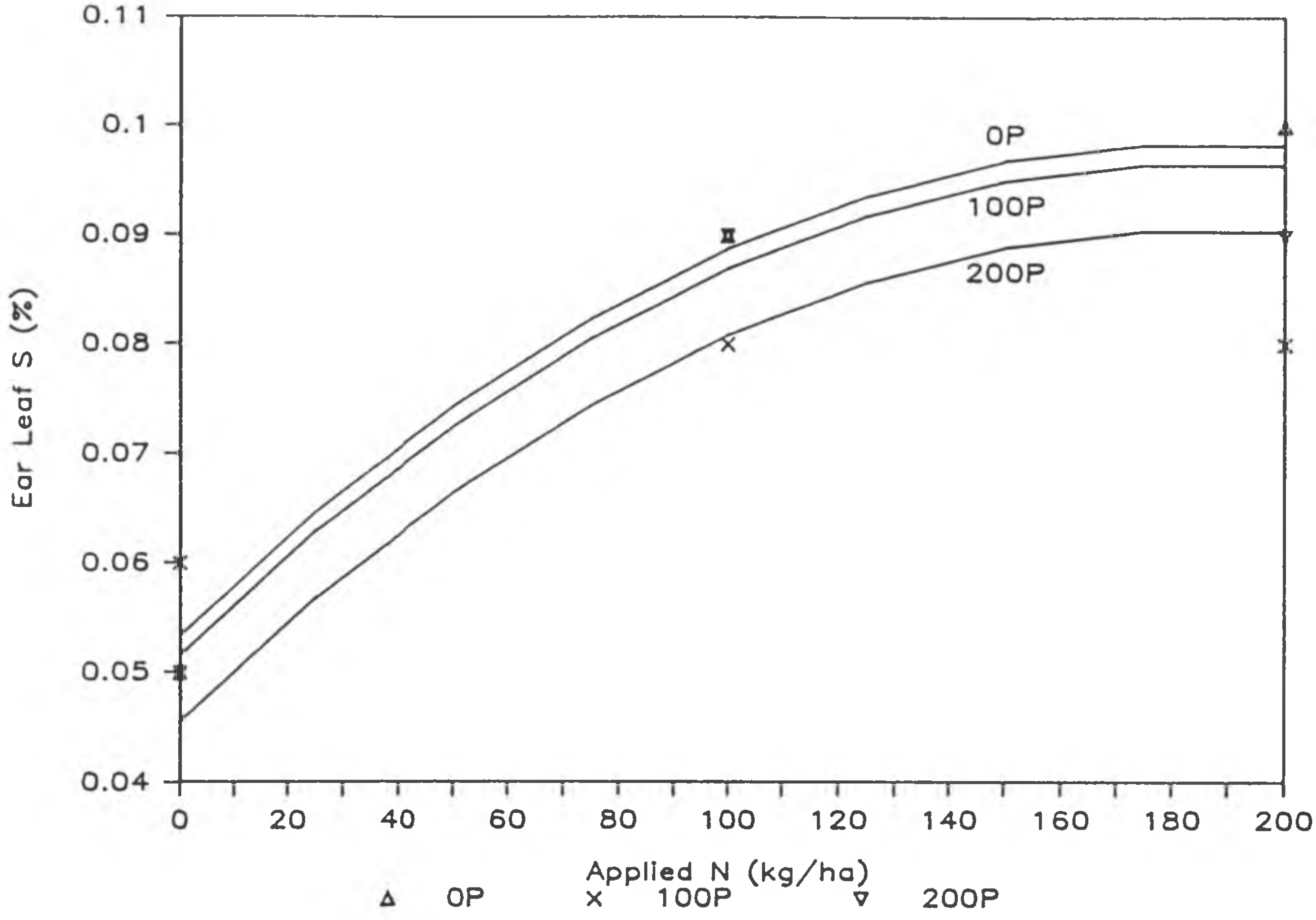


Figure 4.25. The effect of applied N and P on maize ear leaf S.
(R^2 = 0.66. Refer to Appendix B for regression coefficients.)

relationship between the amounts of N and S metabolized in the plants. Data from their greenhouse studies indicate that one part of S was required for every 12 to 15 parts N to ensure maximum production of both dry matter and protein. The N/S ratios of proteins vary slightly because proteins have a defined composition (Mengel and Kirby (1982), and is in the order of 30/1 to 40/1 (Dijkshoorn and van Wijk (1967). These ratios have been also observed with maize (Rendig et al., 1976).

Sulfur in the maize ear leaves may have originated from the soil, the applied farm inputs or the atmosphere. The quantities of S originating from the atmosphere depend on the rainfall, the emission of SO_2 in smoke and the distance from the sea. Because of its nearness to the sea, the experimental site may be well supplied with S as soils in maritime regions are reportedly well supplied with S (Mengel and Kirby, 1982). Dam Kofoed and Fogh (1968) reported that in Denmark an average of 8 to 15 kg S ha^{-1} yr^{-1} is supplied to the soil by precipitation. According to Riehm and Quellmalz (1959) at least the same amount of S, in the form of SO_2, is absorbed directly by crops under conditions where high SO_2 concentrations are present in the atmosphere.

Calcium: The ear leaf concentration of Ca was well correlated with applied N (Table 4.9 and Figure 4.26). When applied N was increased from 0 to 100 kg N/ha, ear leaf Ca remained constant with 100 kg P/ha or increased slightly with 0 and 200 kg P/ha (Figure 4.26). However, when applied N was increased from 100 to 200 kg N/ha, ear leaf Ca concentration increased with all levels of P, but at different rates. With 100 and 200 kg P/ha, ear leaf Ca increased at similar

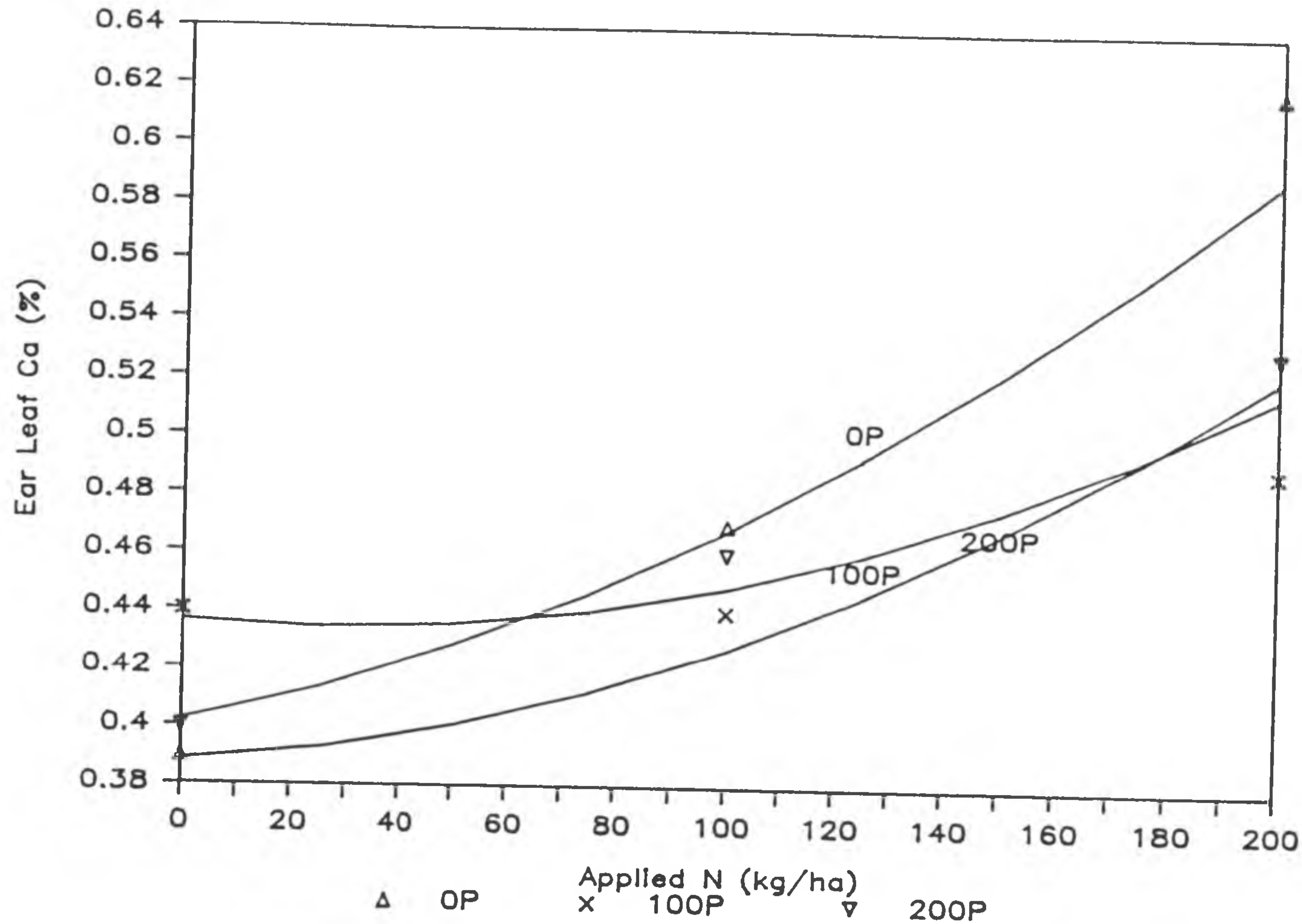


Figure 4.26. The effect of applied N and P on maize ear leaf Ca.
(R^2 = 0.68. Refer to Appendix B for regression coefficients.)

rates while at 0P ear leaf Ca increased at a faster rate giving the highest Ca levels (Figure 4.26).

Iron: The concentration of ear leaf Fe was well correlated with applied N and there was interaction between N and P (Table 4.9 and Figure 4.27). At all levels of applied P, ear leaf Fe increased with increasing rates of applied N (Figure 27). As the rate of N was increased from 0 to 100 kg N/ha, ear leaf Fe concentration increased slightly. However, when applied N was increased from 100 to 200 kg N/ha, the rate of increase in ear leaf Fe did not change much with higher rates of applied P (100 and 200 kg P/ha), but it increased sharply with 0P. Thus, at 200 kg N/ha, the concentration of ear leaf Fe was 142.3ppm Fe for 0P and 106.0 and 105.3ppm Fe, with 100 and 200P respectively.

4.1.2. Responses to the Supplementary Treatments.

Experimental data of this study were divided into three groups (A, B and C) as discussed in the beginning of this chapter. Group B, discussed above, dealt with the effects of N, P, and their interaction. In this section, data of groups A and C will be discussed.

Group A includes only two treatments, the complete and partial controls. Analysis of these treatments was aimed at determining the effect of the K, Zn, Cu and Mo which were applied in the partial control treatment. Data analysis indicated that, for all the response variables measured, the partial control was not significantly different from the complete control. Thus it was concluded that, without N and

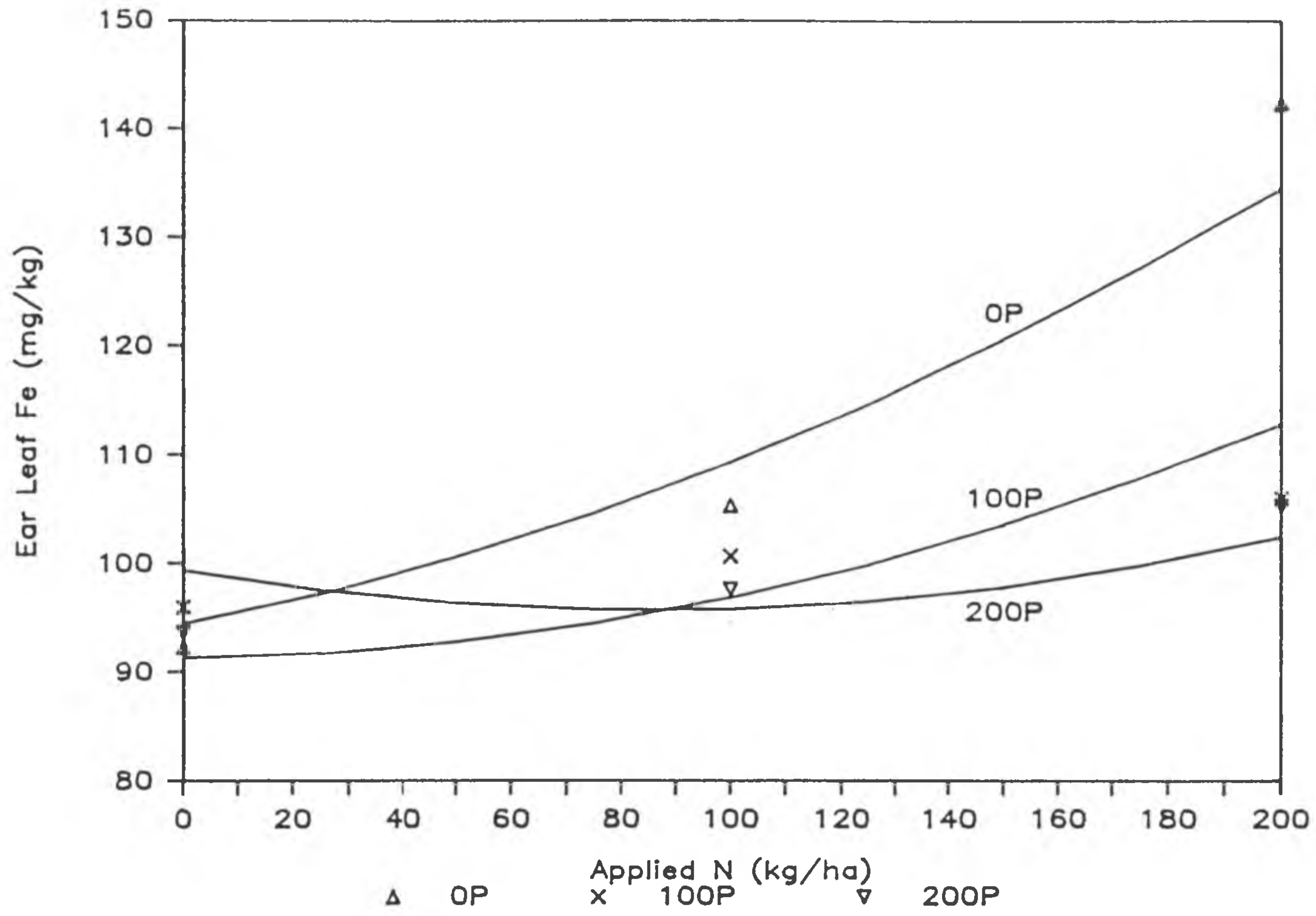


Figure 4.27. The effect of applied N and P on maize ear leaf Fe.
(R^2 = 0.77. Refer to Appendix B for regression coefficients.)

P, there was no effect of the K, Zn, Cu and Mo application over no fertilizer application.

Section 4.1.1 (Responses to Nitrogen and Phosphorous) provides a more extensive discussion of the performance of the partial control, (treatment 0N, 0P). This treatment was found to be not significantly different from that of the complete control. These two control treatments performed poorly compared to the rest of the treatments: they produced lower yields and yield components, shorter and smaller plants that looked yellowish and sickly, and they took a longer time to tassel, silk and mature (Table 4.12).

Group C includes five treatments: treatments 14 (basic: 200N, 200P, blanket treatment, with a planting density of 67,800 plants ha^{-1}), 15 (- Zn), 16 (-Cu), 17 (hi pop: 93,900 plants ha^{-1}) and 18 (+Manure: Chicken Manure added at 16.82 Mg ha^{-1})(Table 1, Chapter III). Results and discussions pertaining to data of Group C are presented below:

Table 4.12. A comparison of the Means of the Response Variables for the Control (Partial and Complete) Treatments and the Whole Experiment.

	Means	
	Controls (Group A)	Whole Experiment
A. Harvest Data		
Grain Yield	0.95	8.11
Stover Yield	2.72	7.47
Earlength	7.53	14.26
100-kernel Weight	20.54	22.19
B. Plant Height		
Height at 24 DAP	20.90	33.60
Height at 57 DAP	68.73	163.02
Height at 119 DAP	154.87	257.05
C. Biomass at Various Stages		
At 31 DAP	9.84	57.05
At 73 DAP	174.09	1,007.09
At 50% Dough (Ears)	115.50	751.44
At 50% Dough (Stover)	283.50	877.06
Ear leaf Weight	13.07	31.21
D. Crop Greenness at 95 DAP	1.00	2.06
E. Physiological Development		
Days to 50% tasselling	79.67	70.19
Days to 50% Silking	93.50	76.55
Days to Maturity	150.00	139.76

4.1.2.1. Final Harvest.

Grain yields (Grain Yld) of the chicken manure treatment (+manure) were significantly higher than those of all the other treatments in the experiment with yields that were 2 Mg higher than the basic treatment (Table 4.13).

It has been shown above that grain yields of this experiment were mainly a function of applied N. Analysis of the chicken manure indicate that the +manure treatment received an additional 260N from the manure in addition to the 200N from applied fertilizer N. As such, it is concluded that the high yield of the +manure treatment was mainly due to its high N content.

Table 4.13. Effect of the Supplementary Treatments on Means of Final Harvest Variables*.

Variables	Basic	-Zn	-Cu	Hi Pop	+Manure
Grain Yld (t/ha)	12.15 B	11.68 BC	10.74 C	11.64 BC	14.15 A
Stover Yld (t/ha)	9.14 A	9.87 A	10.14 A	9.50 A	12.54 A
Fd Earlength (cm)	18.42 AB	16.88 C	17.72 BC	14.17 D	18.93 A
H Kernel Wt (g)	24.08 B	23.31 B	22.89 B	22.32 B	26.30 A

*Means in the same row followed by the same letter are not significantly different at the 0.05 probability level according to the Bayes LSD Test.

Apart from its higher N content, the +manure treatment had other advantages as well. It also received an additional 60P and P has been shown in this experiment to be of importance in the earlier stages of maize growth. Chicken manure also contained 6K, an element which is known to help offset the negative effects of heavy N applications (Arnon, 1974). Calcium, Zn and Cu were also found in chicken manure and these micronutrients may have been of importance for nutrient balance in the +manure treatment because of its high rate of N application, even though they may be of little or no importance for the low N treatments.

It has been known for a long time that all the N in chicken- and other farmyard-manure is not readily available to the plant (Hall, 1909) as some of it will be slowly released into the soil and this can be an advantage where N loss is a problem. However, the value of farmyard manure is not confined only to its fertilizing action. The physical effects upon the texture and water-holding capacity of the soil are equally important. Manure is also valuable for its mulching effect.

Yields of the treatments with higher population density (hi pop) and without Zn (-Zn) were not significantly different from the basic treatment. However, the absence of the Cu component of the blanket treatment (-Cu) resulted in yields that were significantly lower than those of the basic treatment.

There have been numerous reports which show that planting density has a significant effect on the yields of maize (Allessi and Power, 1975; Isfan, 1984; Karlen and Camp, 1985; Krall, et al., 1977; Moll and Kamprath, 1977) and other crops (Hoggard et al., 1978; Lueschen and Hicks, 1977; Parker et al., 1981). The difference in planting densities employed in this experiment (67,800 versus 93,900 plants ha^{-1}) may not have been large enough to result in any significant differences in grain yield. However, these same plant populations may give significant differences in yield under other environmental-, soil- or management conditions because planting densities are known to interact with these factors (Karlen and Camp, 1985). In addition, inadequate amounts of fertilizer for the higher population may also have limited yields.

Even though Zn has been long known to be indispensable for normal growth of plants (Sommer and Lipman, 1926; Sommer, 1928), some studies have shown that Zn fertilization does not always result in increases in grain yield (Stout and Bennet, 1983). The lack of response in grain yield to the Zn treatment in this experiment may indicate that the soil-Zn level was sufficient for maize; the applied Zn was not needed but its application did not result in any significant reduction in grain yield because the level of application was sub-toxic. However, other factors may be involved: for example, it has been reported that maize genotypes differ in their uptake and use of Zn (Clark, 1978; Shukla and Raj, 1976), and temperature has been shown to affect both the chemistry of Zn in the soil and utilization of Zn by the plants (Bauer and Lindsay, 1965; Edwards and Kamprath, 1975; Ellis et al., 1964; Martin et al., 1965; Ozanne, 1955). Therefore, it is not surprising that Isarangkura et al. (1978) reported that grain yield of maize showing symptoms of Zn deficiency are variable: in some instances, symptoms are persistent and yields are low, whereas in other years or in other fields, plants appearing equally stressed may recover rapidly after 3 to 6 weeks, with little or no reduction in grain yields.

Grain yields in this experiment were significantly lower without the addition of Cu fertilizer indicating that the level of soil-Cu in the experimental area may not have been sufficient for maize. This is a reasonable proposition because analysis of pre-plant soil indicates that the experimental soil had a Cu content of 0.40 mg kg^{-1} while 4 to 6 mg kg^{-1} is considered as the minimum requirement for maximum production on mineral soils (Knezek, 1972).

Stover yields (Stover Yld) were not significantly different among the five treatments (Table 4.13). However, it is interesting to note that the largest yield difference was between the +manure and basic treatments.

The +manure and the -Cu treatments gave filled earlengths (Fd Earlength) that were not significantly different from those of the basic treatment, while those of the -Zn and the hi pop treatments were significantly shorter than those of the basic treatment (Table 4.13). These results indicate the importance of Zn and planting density on the filled earlength of maize.

Hundred kernel weight (H Kernel Wt) of the +manure treatment was significantly higher than those of the other treatments which did not differ significantly (Table 4.13). Regressional analysis indicate that the 100-kernel weight data for group B was influenced by applied N and P (R^2 for NP model = 0.501), but mainly by N (R^2 = 0.463). As such, the +manure treatment, with its higher inputs of N and P is expected to produce heavier kernels.

4.1.2.2. Plant Height.

The +manure treatment resulted in significantly taller plants than those of the basic treatment at 24 DAP (height A) and at 57 DAP (height B); however, at 119 DAP (height C), plant heights of these two treatments were not significantly different (Table 4.14). Data analyses for group B indicate that N was important for plant height at all growth stages (heights A, B and C) while P was important only at the early stage of crop growth (height A). Therefore, the +manure treatment, with its higher rates of N and P is expected to produce taller plants. However, at height C, plants of the +manure treatment, which matured the earliest, were approaching maturity and further increases in plant heights were probably limited by genetic and other factors apart from N and P.

Table 4.14. Effect of the Supplementary Treatments on Mean Plant Height of Maize*.

Variable	Basic	-Zn	-Cu	HI POP	+Manure
Height A (cm)	38.88 B	45.65 AB	42.37 AB	39.53 B	48.72 A
Height B (cm)	206.48 D	228.27 B	214.38 C	207.67 CD	267.33 A
Height C (cm)	302.87 AB	309.63 AB	305.00 AB	297.03 B	325.67 A

*Means in the same row followed by the same letter are not significantly different at the 0.05 probability level according to the Bayes LSD Test.

At height A, only the chicken manure treatment resulted in significantly taller plants for reasons discussed above. At height B, the -Zn and -Cu, as well as the +manure treatment, resulted in significantly taller plants. This indicates that the Zn and Cu that were applied as components of the blanket application may not have been conducive to increased plant heights; however, no similar effect of Zn or Cu on plant height was found in the literature.

At height C, there were no significant differences among the plant heights of the 5 supplementary treatments. This trend was also observed in the field: when the maize plants were young, it was much easier to visually observe the differences among the treatments with respect to plant height. However, as the plants grew older, especially as they approached maturity, the differences in plant heights seem to have disappeared. Apparently, factors other than N and P or the supplementary treatments limited plant height.

The effect of the hi pop treatment on plant height was not significantly different from that of the basic treatment at all plant height measurements. The differences in planting density may not have been large enough to result in height differences with the management practices carried out for this experiment.

4.1.2.3. Growth (Increase in Plant Height).

Trends in growth rates A, B and C (Table 4.15) are similar to those for plant heights A, B and C (Table 4.14). Growth rate AB, the rate of daily increase in plant height from height A to height B, followed a pattern similar to that observed for height B: the +manure and -Zn treatments had significantly faster rates of increase in plant height than the basic treatment; however, the -Cu treatment was not significantly different from the basic treatment. The lack of any significant difference among the treatments at growth rate AC was simply a reflection of the non-significant difference among the treatments at height C. However, the new piece of information provided by the data on growth rates (Table 4.15) is that growth rate BC for the +manure treatment was significantly lower than those of the others which were not significantly different. This difference was probably due to the faster growth of the +manure treatment because of its higher rates of applied N and P which resulted in reduced growth rate during the BC period because it started to mature and the focus on growth shifted from the vegetative to the reproductive tissues of the plant.

Table 4.15. Effect of the Supplementary Treatments on the Mean Increase in Plant Height (Growth Rate) of Maize.*

Variable	Basic	-Zn	-Cu	Hi Pop	+Manure
Growth Rate A	17.07 B	20.01 AB	17.44 B	18.60 AB	21.27 A
Growth Rate B	35.94 C	39.22 B	36.58 C	37.02 C	46.12 A
Growth Rate C	25.45 A	26.02 A	25.63 A	24.96 A	27.37 A
Growth Rate AB	49.42 C	53.82 B	51.58 BC	48.60 C	64.37 A
Growth Rate AC	26.66 A	26.66 A	26.81 A	25.72 A	27.98 A
Growth Rate BC	15.30 A	12.92 A	14.38 A	14.19 A	9.26 B

*Means in the same row followed by the same letter are not significantly different at the 0.05 probability level according to the Bayes LSD test.

Growth rates for the -Cu and hi pop treatments were never significantly different from that of the basic treatment, indicating that the addition of Cu and increased planting density did not have any significant effect on the increase in plant height.

4.1.2.4. Biomass.

At 31 DAP (Biomass A), the maize plants had not yet displayed any significant differences among the treatments; however, at 73 DAP (Biomass B), biomass of the +manure treatment was significantly greater than those of the others except the basic, while at the dough stage, the +manure treatment also had higher biomass than the basic treatment (Table 4.16). The better performance of the +manure treatment was probably partly due to its higher rates of applied N and P. As has been discussed, N had considerable influence on biomass over much of the crop's growth while P was of importance only during the early part of the crop. However, the effect of the +manure treatment cannot be attributed to N and P alone as previously discussed in regard to the effect of the treatment on grain yield.

The -Zn treatment did not differ significantly from the basic treatment at 31 and 73 DAP indicating that Zn had little effect on biomass production (Table 4.16). On the other hand, the -Cu and hi pop treatments had significantly smaller biomass at 73 DAP (-Cu and hi pop) and at the dough stage (hi pop) (Table 4.16). This indicates that the applied Cu may have contributed to greater biomass production, and that the higher planting density of the hi pop treatment may be partly responsible for its lower biomass production.

Table 4.16. Effect of the Supplementary Treatments on the Mean Biomass of Maize.*

Biomass	Control		-Zn		-Cu		Hi Pop		+Manure	
A	98.4	A	97.3	A	102.1	A	99.2	A	141.2	A
B	1573.2	AB	1434.8	B	1296.4	C	1063.5	C	1689.2	A
C(Ears)	1029.0	B	nd		nd		769.0	C	1420.0	A
C(Stover)[a]	1156.0	B	nd		nd		965.5	B	1507.5	A
Eleaf Wt	40.4	BC	46.5	B	44.8	B	34.9	C	53.6	A

*Means in the same row followed by the same letter are not significantly different at the 0.05 probability level according to the Bayes LSD Test.

[a]nd = not determined.

4.1.2.5 Growth Rate of Biomass.

For growth rate AB (31 to 73 DAP), the plants of the +manure treatment grew significantly faster than plants of all the other treatments (Table 4.17). This is probably due mainly to the higher rates of applied N and P of the +manure treatment.

Table 4.17. Effect of the Supplementary Treatments on the Mean Increase in Biomass (Growth Rate) of Maize Biomass.*

Growth Rate	BASIC	-Zn	-Cu	HI POP	+MANURE
A	A	A	A	A	A
B	AB	B	C	C	A
AB	35.11 AB	31.84 BC	28.30 C	23.42 D	36.86 A

*Mean values for growth rates A and B are proportional to those of biomass A and B of Table 5. Same letters in the same row indicate that the corresponding treatments are not significantly different at the 0.05 probability level according to the Bayes LSD Test.

At growth rate AB, the -Zn treatment was not significantly different from the basic treatment while the -Cu and hi pop treatments had significantly lower growth rates. These differences in growth rates are reflected in the variability in biomass recorded at 73 DAP (biomass B).

4.1.2.6. Phenological Development.

The five supplementary treatments were not significantly different with regard to greenness, brownness and the period between silking and tasselling (Table 4.18). These response variables have limited values (e.g., it is difficult to have more than three reliable values for crop color), hence they are not good variables to measure differences in the effects of the five supplementary treatments, since had received comparatively high levels of N and P.

The time required to reach 50% tasselling and silking and physiologic maturity was significantly shorter for the +manure treatment than for the basic and the other supplementary treatments. This is probably partly due to the more rapid early growth of plants in the +manure treatment, as some nutritional problems affecting plants at an early stage cannot be rectified later; hence, even though the non-manured treatments appeared to catch up in terms of plant height and biomass, they still lagged behind in the reproductive, and other aspects of production.

Days required by the plants to reach 50% tasselling were not significantly different among the -Cu, -Zn, hi pop, and basic treatments (Table 4.18), indicating that these treatments may not have been important in determining days to 50% tasselling. However, the -Zn treatment required a significantly shorter time to silk (1.9 days), indicating that the applied Zn may have caused a slight delay in silking. The -Cu treatment resulted in a significant delay in maturity which is quite small.

Table 4.18. Effect of the Supplementary Treatments on the Mean Phenological Development of Maize*.

Variable	Control	-Zn	-Cu	Hi Pop	+Manure
Tas	67.00 A	65.00 A	66.00 A	65.00 A	61.33 B
Sil	69.67 A	68.00 B	69.00 AB	68.67 AB	64.33 C
Sil-Tas	2.67 A	3.00 A	3.00 A	3.67 A	3.00 A
Green	2.83 A	2.67 A	3.00 A	2.67 A	3.00 A
Brown	2.33 A	2.50 A	2.50 A	2.67 A	2.33 A
Dd Lvs	10.00 B	9.00 B	11.00 B	13.67 A	4.33 C
Maturity	132.67 B	132.67 AB	133.33 A	132.00 B	129.00 C

*Means in the same row followed by the same letter are not significantly different at the 0.05 probability level according to Bayes LSD Test.

The +manure treatment had significantly fewer dead leaves than all the other supplementary treatments at 90 DAP. This is probably due to the higher rates of N, P, and other nutrients in the +manure treatment which kept the plant leaves well nourished. On the other hand, the hi pop treatment had significantly more dead leaves than the other supplementary treatments which is probably due to the fact that plants in the hi pop treatment experienced the severest competition for water and nutrients. As mentioned earlier, amounts of N and P applied were probably inadequate for the higher population and nutrients were translocated from the older leaves to developing grain resulting in the early death of the lower leaves.

4.1.2.7. Ear Leaf Analysis.

The concentrations of ear leaf Cu, Al, Mn and Fe were not significantly different among the 5 supplementary treatments (Table 4.19). However, ear leaves of plants that received the +manure treatment had significantly higher concentrations of N, P, K, Zn, Mg, S, and Cl than the basic treatment. This is not surprising because analysis of chicken manure revealed the presence of these nutrients. However, the +manure treatment had a significantly lower concentration of ear leaf Si, the absorption of which, may have been suppressed by anions of N, P, S, or Cl that were supplied by the chicken manure.

The hi pop ear leaves had significantly lower concentrations of N, P, K, Ca, Mg, and S compared to the basic treatment. This is expected since there was considerable competition for nutrients in the hi pop treatment which resulted in lower concentrations of nutrients.

The -Zn treatment had significantly lower concentrations of N, P, and K compared with the basic treatment. The absence of Zn may have adversely affected the absorption of N, P, and K. In field experiments on a dark-brown clay (pH 5.8) in Southern Rhodesia, Thompson (1962) observed that increasing the N supply increased Zn contents. Many investigators that worked with maize have established that applied P may depress the uptake of Zn or vice versa, and this effect is particularly marked on soils rich in native P (Bingham, 1963). In the current experiment, it is interesting to note that the Zn concentration was not significantly different in the -Zn and basic treatments, although it was lower in the -Zn treatment.

The -Cu treatment resulted in an ear leaf P concentration that was lower than that for the basic treatment. This suggests that applied Cu may have enhanced the extraction of P, however, Bingham (1963) reported that excessive P fertilization, generally, reduces the availability of Cu.

Table 4.19. Effect of the Supplementary Treatments on the Mean Concentration of Elements in Maize Ear Leaves at 50% Silking*.

Element	Control	-Zn	-Cu	Hi Pop	+Manure
	..................(%)..................				
N..........	1.87 B	1.66 C	1.82 B	1.60 C	2.38 A
P..........	0.15 B	0.14 C	0.14 C	0.12 D	0.21 A
K..........	1.59 B	1.48 CD	1.56 BC	1.46 D	1.76 A
Ca.........	0.53 AB	0.48 BC	0.56 A	0.46 C	0.54 AB
Mg.........	0.17 B	0.16 BC	0.16 BC	0.15 C	0.20 A
S..........	0.09 B	0.09 B	0.09 B	0.08 C	0.11 A
Si.........	1.24 A	1.25 A	1.07 AB	1.15 AB	0.96 B
Cl........	0.11 BC	0.10 C	0.12 B	0.10 C	0.20 A
	..................(mg kg^{-1})..................				
Cu.........	6.33 A	4.67 A	4.00 A	3.67 A	3.67 A
Zn.........	24.67 BC	21.67 C	26.67 B	24.00 BC	33.33 A
Al.........	104.67 A	82.67 A	165.00 A	91.33 A	72.33 A
Mn.........	125.00 A	121.33 A	134.67 A	120.33 A	141.33 A
Fe........	105.33 A	105.33 A	109.00 A	107.67 A	106.00 A

*Means in the same row followed by the same letter are not significantly different at the 0.05 probability level according to the Bayes LSD Test.

4.2. Soil Analyses.

As previously discussed (Chapter III, Section 3.4.1.4.), three soil samples were collected during the study. The first was a preplant sample collected from each of the 54 plots, the second was a "preplant" profile sample from each replicate while the third was a post-harvest sample from each plot. Summaries of the first two samples have been presented in Section 1 of Chapter III in which the preplant conditions of the experimental site were discussed. However, in this section, the emphasis will be on the post-harvest conditions of the experimental soil.

4.2.1. Overall Fertility Status.

In some respects, the overall fertility of the soil at the experimental site changed considerably during the period of the experiment. There was considerable reduction in the average soil N level over all plots during this period (Table 4.20) despite the fact that N was added at an average of 150 kg ha^{-1} in the experiment. The reduction in soil N was probably due to the fact that maize has a high N requirement.

There was an increase in the average level of soil P during the experiment which is not surprising because the initial level of soil P is considered adequate for maize. Furthermore, P was a major nutrient input in the experiment which was added at an average rate of 150 kg ha^{-1}.

Table 4.20. Soil Analyses: Comparison of Preplant and Postharvest Means for the Experimental Site[a].

Analysis[b]	Preplnt	Psthvst	%Increase (+)	OR %Decrease (-)
NH_4-N (mg kg^{-1})...............	14.66	3.62		-75.31
NO_3-N (mg kg^{-1})...............	4.05	1.74		-57.04
Mod Truog-P (mg kg^{-1}).........	31.91	60.01	+88.72	
Mg (cmol (+) kg^{-1}).............	1.18	1.96	+66.10	
K (cmol (+) kg^{-1}).............	0.84	1.13	+34.52	
Na (cmol (+) kg^{-1}).............	0.17	0.21	+23.53	
Cu (cmol (+) kg^{-1}).............	0.40	0.43	+ 7.50	
Ca (cmol (+) kg^{-1}).............	5.15	5.34	+ 3.69	
pH (1:1 H_2O)...................	5.57	5.74	+ 3.05	
pH (1:1 KCl)......................	5.02	5.14	+ 2.39	
Zn (cmol (+) kg^{-1}).............	0.25	0.24		- 4.00

[a]Values are means over the 54 plots in the experiment.

[b]All original analyses were carried out separately for each of the 54 plots except for Cu and Zn for which the preplant analyses were carried out on the composite samples collected from each replicate.

Potassium was added at a rate of 100 kg P ha^{-1} to all plots except the three complete control plots which did not receive any fertilizer application. This K application was probably responsible for the higher level of soil K found at the end of the experiment since the soil had a fairly high level of K originally.

There was a considerable increase in soil Mg which is surprising because Mg was not added in the experiment except in the treatment receiving chicken manure. Chicken manure contained 98.8 mg Mg kg^{-1} (Table 3.3) but the increase in the level of postharvest-soil Mg for this treatment was not significantly different from the increase in other treatments, hence the addition of chicken manure alone cannot account for the recorded increase in soil Mg. Furthermore, there were only three chicken manure plots out of the 54 plots in the experiment. However, the increase may be explained in terms of the measured increase in soil pH which is known to increase the availability of Mg within a soil pH range of 4.0 to 7.0 (Foth 1984). As discussed by Foth (1984), soil pH is related to the percentage of base saturation and when base saturation is less than 100 percent, an increase in pH is associated with an increase in the amount of Ca and Mg in the soil solution since they are usually the dominant exchangeable bases. Thus, the slight increase in soil Ca in the experimental area may be explained in terms of pH as well.

The increase in soil Na may be related to, or may even be the cause of the increase in soil pH. The maize crop was planted at the end of the rainy season at which time soil Na was low due to leaching while the crop was harvested towards the end of summer when high evaporation would allow the leached Na to rise closer to the soil surface.

Copper was added at a rate of 2.5 kg Cu ha^{-1} to 48 of the experiment's 54 plots which likely accounted for the increase in the average soil Cu content over the experimental period. There was practically no change in the average level of soil Zn even though it was added at a rate of 15.0 kg ha^{-1} to 48 of the experiment's 54 plots.

4.2.2. Response to Nitrogen and Phosphorous.

The effects of N and P on the postharvest levels of soil N and P were determined by analysis of variance carried out on data from treatments 2 to 14. The only significant relationship found was that between applied P and postharvest soil P, and between applied P and the percentage increase in soil P (Figures 4.28 and 4.29). The postharvest level of soil P increased with the level of P applied for all levels of N applied. The amount of applied P required to meet the maize plant's requirement was about 15 kg ha^{-1} for the 0 and 100 kg N ha^{-1} treatments and about 40 kg ha^{-1} for the 200 kg ha^{-1} treatment (Figure 4.29). Soil P was apparently sufficient to supply most of the plants' requirements as higher rates of applied P led to increased soil P levels.

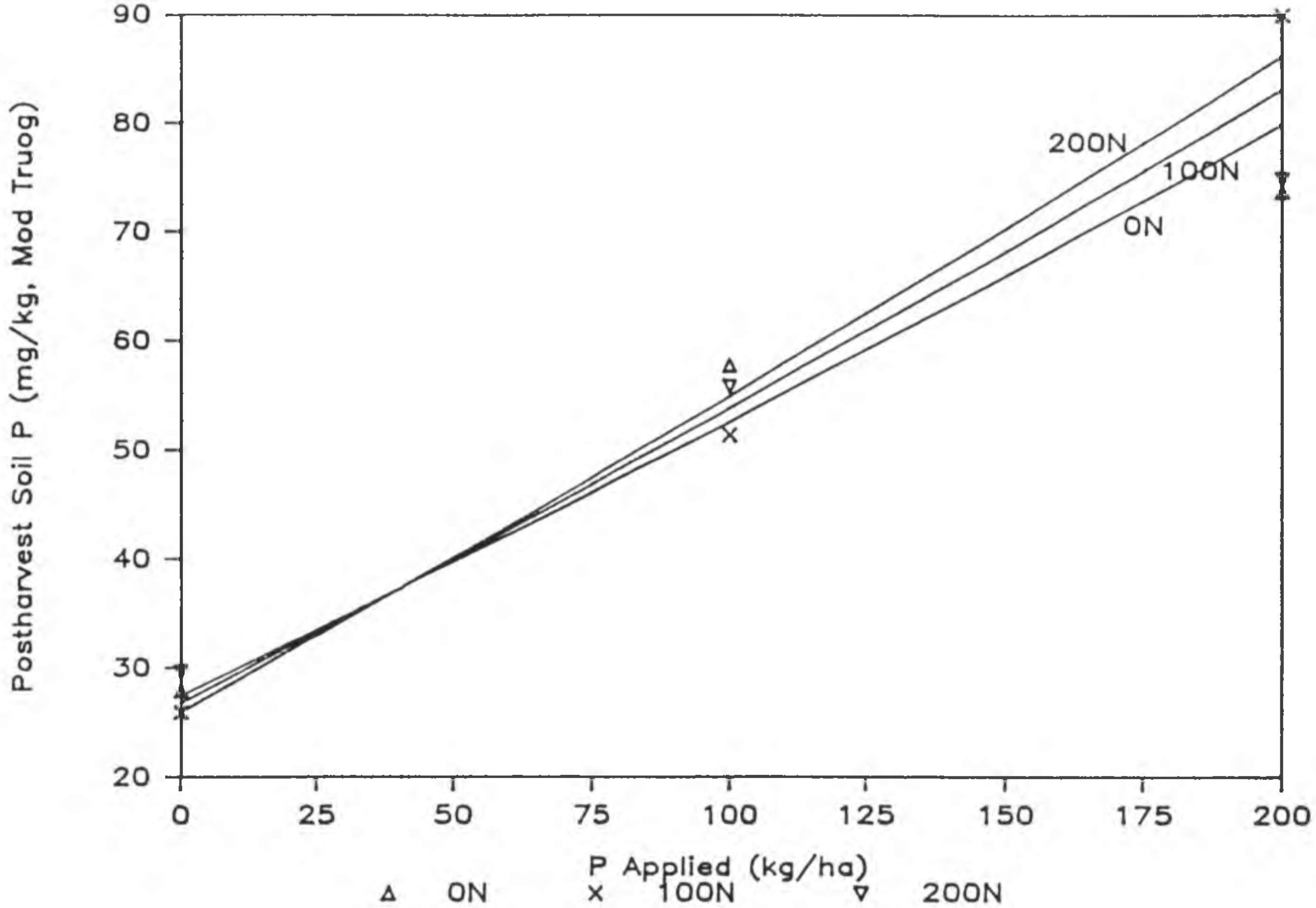


Figure 4.28. The effect of Applied P on Postharvest Soil P.

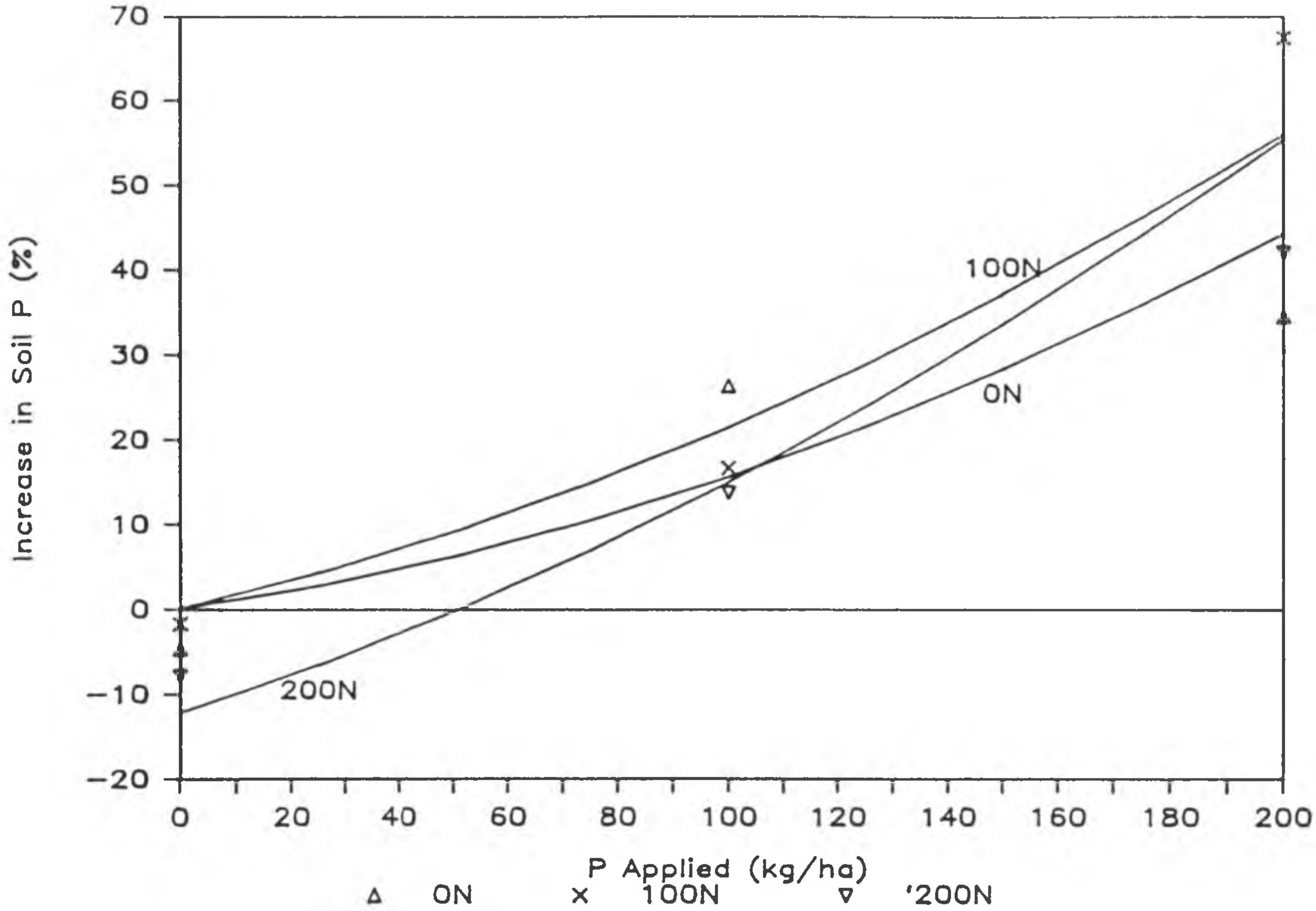


Figure 4.29. The effect of Applied P on the Increase in Soil P.

4.2.3. Response to the Supplementary Treatments.

In the complete control plots there was a decrease in the soil levels of N, P, Zn and Cu while there was an increase for the other elements (Table 4.21).

Maize plants in treatment 1 had to extract all required nutrients from those naturally present in the soil. A comparison of Tables 4.20 and 4.21 reveals that the levels of postharvest soil nutrients in treatment 1 were lower than the average values for the whole experiment. This is true for all elements tested except for the average levels of soil Mg which were about the same for both sets of treatments: it was 1.96 cmol (+) kg^{-1} for the whole experiment and 1.99 for treatment 1. However, the greatest reduction occurred for the elements most important in the nutrition of maize: N, K, and P.

The increase in the level of soil Na may have caused the increase in soil pH which contributed to the increased availability of Mg, Ca, and K during the experiment.

Table 4.22 shows the postharvest levels of soil elements and the % increase or decrease in these levels over the preplant levels for the supplementary treatments. (All the supplementary treatments, as well as the basic treatment, received the highest levels of N and P.)

Table 4.21. Soil Analyses: Comparison of Preplant and Postharvest Means of the Complete Control Plots[a].

Analysis	Preplant	Postharvest	% Increase (+) or % Decrease (-)
NH_4-N (mg kg^{-1})	14.77	2.91	- 80.4
NO_3-N (mg kg^{-1})	3.69	0.00	-100.0
Mod Truog P (mg kg^{-1})	24.30	23.91	- 1.5
Mg (cmol (+) kg^{-1})	1.14	1.99	+81.8
K (cmol (+) kg^{-1})	0.66	0.77	+16.7
Na (cmol (+) kg^{-1})	0.17	0.20	+17.6
Cu (cmol (+) kg^{-1})	0.40	0.33	- 17.5
Ca (cmol (+) kg^{-1})	4.68	4.86	+ 4.3
pH (1:1 H_2O)	5.59	5.88	+ 5.4
pH (1:1 KCl)	5.02	5.19	+ 4.0
Zn (cmol (+) kg^{-1})	0.25	0.05	- 80.0

[a]Values are means of 3 replicates.

Table 4.22. The Effects of the Supplementary Treatments on the Mean Levels of Soil Elements.

	TREATMENTS[a]									
Analy-	T14. Cntrl		T15. -Zn		T16. -Cu		T17. Hi Pop		T18. Man	
-sis[b]	PH	%I	PH	%I	PH	%I	PH	%I	PH	%I
P......	75	128	77	140	60	146	77	135	143	388
NH_4-N..	1.8	-87	1.5	-90	1.8	-85	5.6	-69	5.8	-58
NO_3-N[c].	1.7	-76	2.3	-38	0	-100	0	-100	16	186
Ca.....	5.1	2.0	5.1	6.3	4.8	-2.0	5.1	11	8.3	51
Mg.....	2.1	91	2.2	100	1.9	73	2.1	75	2.1	75
Na.....	.20	11	.18	12	.19	12	.18	13	.19	19
Cu.....	.43	nd	.46	nd	.33	nd	.44	nd	.48	nd
K......	1.2	48	1.4	65	1.2	60	1.5	65	1.6	63
pH(H_2O)	5.8	5.5	5.6	3.7	5.7	0	5.6	-1.8	5.6	-1.8
pH(KCl)	5.2	2.0	5.1	4.1	5.2	2.0	5.1	2.0	5.2	2.0
Zn.....	.27	nd	.22	nd	.13	nd	.37	nd	.40	nd

[a]T14 (treatment 14), considered here as a control, includes 200N and P and the blanket application. T15, T16, T17 and T18 are the same as T14 except that T15 had a partial blanket application without Zn, T16 had a partial blanket application without Cu, T17 had a higher plant population (93,900 plants ha^{-1} instead of 67,800 plants ha^{-1}) and T18 had 16.82 Mg ha^{-1} fresh chicken manure (14.7%moisture) added. PH = postharvest soil analysis; %I = %increase (or decrease, -,) in postharvest soil analysis over preplant analysis.

[b]Soil analyses: P = Mod Truog P (mg kg^{-1}); NH_4-N and NO_3-N are in mg kg^{-1} while Ca, Mg, Na and K are in cmol (+) kg^{-1}; %I for Cu and Zn were not determinable (nd) because of insufficient data.

[c]Preplant soil analyses: T16 = 3.9, T17 = 2.2.

The increases in levels of soil P, NO_3-N and Ca are far greater in the manure treatment than for the other treatments (Table 4.22). This is not surprising because chicken manure contained considerable quantities of these elements (Table 3.3).

4.3. Meteorological Data.

The maize crop for this experiment was planted on April 30, 1985. Individual plots were harvested as they reached physiologic maturity and the last treatment was harvested on October 3, 1985. This section will present a summary of meteorological data collected for the months of April to October to provide information regarding the agro-meteorological conditions of this experiment. Data were collected for solar radiation, temperature (maximum and minimum), pan evaporation, relative humidity (maximum and minimum) and rainfall. The full text of meteorological data collected is presented in Appendix D.

Table 4.23. Meteorological Data (Monthly Means) for Maize Growing Period.

Month (1985)	Sol Rad (ly)	Temp (^{o}C) Max	Min	Pan Evap (mm)	Rel Hum (%) Max	Min	Rainfall (mm)
April	455	24.3	16.4	1.95	94.2	52.4	2.52
May	445	24.7	18.0	2.20	93.5	53.0	3.41
June	483	26.0	18.9	2.64	94.7	48.9	8.85
July	480	28.7	21.0	2.94	94.6	51.1	2.16
August	357	28.6	20.4	2.59	94.4	51.2	1.93
September	468	28.0	19.8	2.11	94.1	53.2	8.50
October	426	26.6	20.1	1.98	93.1	56.1	17.33

V. SUMMARY AND CONCLUSIONS.

5.1. Summary.

An N by P experiment was conducted at the University of Hawaii's Poamoho Experimental Farm on Oahu, Hawaii to determine the nutrient (N, P, Cu, and Zn) requirements of X304C maize that was planted on

Increasing N from 0 to 200 kg ha^{-1} increases grain and stover yield of maize, as well as filled earlength, 100-kernel weight, plant height, biomass, the rates of increase in plant height and biomass, ear leaf weight, crop greenness during crop growth and brownness towards maturity, and the concentration of ear leaf N, Mn, S, Ca, and Fe. However, this addition of N resulted in a reduction in days required for maize to reach 50% tasseling and 50% silking, and also a reduction in the period between tasseling and silking, the number of days required for physiologic maturity, and the occurrence of dead leaves during crop growth.

There was no significant response to P, probably, because of the high level of soil-P. However, P appeared to have an influence on plant height, biomass and the rates of increase of these two variables in the early stage of crop growth.

The addition of chicken manure resulted in increased grain and stover yield and in responses that were similar to adding N. The beneficial effect of manure may be mainly due to the effect of its N and P components.

Increasing planting density from 67,800 to 93,900 plants ha^{-1} had no significant affect on grain and stover yield and on most of the other response variables. However, it significantly reduced filled earlength, biomass per plant and the concentration of ear leaf N, P, K, Ca, Mg, and S. On the other hand, the higher planting density resulted in significantly more dead leaves per plant.

The -Zn treatment did not have any significant effect on grain or stover yield but it resulted in significantly shorter filled earlengths, greater plant height at 57 DAP, less time to 50% silking and a reduction in the concentration of ear leaf N, P and K.

There was a significant reduction in grain yield with the -Cu treatment but stover yield was not affected. Other significant effects of the treatment include taller plants at 57 DAP, lower biomass at 73 DAP, lower concentration of ear leaf P and a shorter time to maturity.

The complete control treatment performed very poorly and the addition of a blanket treatment of K, Cu, Zn and B in the partial control did not result in any significant change.

5.2. Conclusion.

There was not sufficient N added to realize the yield potential of maize under the environmental, soil and management conditions of this experiment. On the other hand, there was an excessive amount of P application. Application rates of 0 to 300N and 0 to 100P would have been better, because it would have shown the whole range of response to the inputs: from low through sufficient to excessive levels of application.

APPENDIX A. Mean Square for Error (MSE) for the 3 Regression Models[a].

Appendix A.1. MSE - Final Harvest.

Response Variable	N Model	P Model	NP Model[b]
Grain Yield	0.781	16.710	0.814[NS]
Stover Yield	1.657	7.577	1.741[NS]
Filled Earlength	107	1408	100[nd]
100-Kernel Weight	1.755	3.199	1.778[NS]

Appendix A.2. MSE - Plant Height.

Height A	30.80	34.60	18.01*
Height B	250	2187	173*
Height C	305	2603	260*

Appendix A.3. MSE - Rate of Increase in Plant Height.

Rate A	4.445	5.137	1.877*
Rate B	6.570	61.05	3.744*
Rate C	2.154	18.39	1.839*
Rate AB	17.04	159.51	15.42[NS]
Rate AC	2.636	22.56	2.560[NS]
Rate BC	4.062	4.394	4.046[NS]

Appendix A. Mean Square for Error (MSE)

for the three Regression Models. (cont.)

Appendix A.4. MSE - Biomass.

Response Variable	N Model	P Model	NP Model
Biomass A	875	771	505*
Biomass B	37,723	226,066	16,691*
Biomass C (Stover)	20,825	66,085	15,142nd
Biomass C (Ears)	12,979	87,967	10,360nd
Earleaves	9.757	109.32	9.599^{NS}

Appendix A.5. MSE - Growth Rate of Total Above-Ground Biomass.

Response Variable	N Model	P Model	NP Model
Growth Rate A	91.04	80.21	52.56*
Growth Rate B			
Growth Rate AB	20.56	121.57	7.004*

Appendix A.6. MSE - Phenological Development.

Response Variable	N Model	P Model	NP Model
Days to 50% Tasseling (Tas)	4.469	15.76	2.605*
Days to 50% Silking (Sil)	6.593	61.24	3.850*
Period between Tas and Sil	3.562	19.40	3.630^{NS}
Crop Greenness	0.0875	0.5739	0.0943^{NS}
Crop Brownness	0.1863	0.2328	0.1125*
Dead Leaf Count	5.739	9.956	5.557^{NS}
Days to Physiological Maturity	14.74	33.78	15.03^{NS}

Appendix A. Mean Square for Error (MSE) for the three Regression Models. (cont.)

Appendix A.7. MSE - Earleaf Analysis.

Response Variable	N Model	P Model	NP Model
N[c]	241	1180	186[NS]
P[c]	11.79	12.73	11.39[NS]
K[c]	102	128	95[nd]
Ca[c]	20.28	45	16.51*
Mg[c]	19.12	21.57	19.23[NS]
S[c]	1.617	4.096	1.538[NS]
Si[c]	352	413	287[nd]
Cl[c]	4.662	3.11	2.904*
Al	2,679	2,971	2,770[nd]
Mn	153.73	455	132.01*
Fe	105.01	144.93	45.33*
Zn	88.02	93.11	87.75[NS]
Cu	6.3493	5.8166	6.3128[nd]

[a]Model N: $Y = b_0 + b_1N + b_2N^2$;
Model P: $Y = b_0 + b_1P + b_2P^2$;
Model NP: $Y = b_0 + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP$.

[b]Differences between MSE values of N and NP models were significant at the 5% level (*), not significant (NS) or not determined (nd). Test of significance, by comparison of Required F (i.e., $F_{0.05,\ \text{diff df},\ \text{FM Error df}}$) with Actual F (i.e., (Diff MS)/(Error $MS_{F\ M}$), where FM=Full Model, diff=difference, FM vs. Reduced Model.

[c]Actual MSE value = Given MSE value X 10^{-4}.

Appendix B. Regression Coefficients for the NP Model

Appendix B-1. Regression Coefficients - Final Harvest

Response Variable	b_0	b_1	b_2	b_3	b_4	b_5	r^2
Grain Yield	1.006	0.0896001	-0.0001792	0.0038429	0.0000008	-0.0000255	0.955
Stover Yield	2.6015	0.0644146	-0.0001527	0.0058087	-0.0000022	-0.0000328	0.791
Filled Ear length	79.9568	0.8964	-0.0020364	-0.0267329	0.0004636	-0.000298	0.935
Kernel Weight	20.4028	-0.0017827	0.0000643	0.0122077	-0.0000664	0.0000261	0.501

Appendix B-2. Regression Co-Efficients - Plant Height

Height A	20.2837	0.0946542	-0.0002804	0.0930113	-0.0003087	0.0001359	0.664
Height B	67.9332	0.9970	-0.0021625	0.2893	-0.0009417	0.0001141	0.931
Height C	157.1077	1.2203	-0.0028221	0.3121	-0.0009204	-0.0004182	0.911

Appendix B.3. Regression Coefficients - Rate of Increase in Plant Height

Rate A	8.9593	0.0421742	-0.0001255	0.0411028	-0.0001352	0.0000557	0.783
Rate B	11.9952	0.1619	-0.0003341	0.0541750	-0.0001798	0.0000238	0.947
Rate C	13.2014	0.1026	-0.0002371	0.0262244	-0.0000773	-0.0000352	0.911
Rate AB	14.0679	0.2671	-0.0005604	0.0561343	-0.0001793	-0.0000058	0.914
Rate AC	13.8198	0.1137	-0.0002567	0.0221238	-0.0000617	-0.000056	0.898
Rate BC	14.1545	0.0354537	-0.0001048	0.0036061	0.0000034	-0.0000844	0.176

Appendix B.4. Regression Coefficients - Biomass

Biomass A	14.009	0.1987	-0.0008167	0.0581296	0.0001217	0.0015437	0.578
Biomass B	185.6338	7.5685	-0.0153105	-0.3691	0.0068821	0.070549	0.949
Ear leaf weight	12.7649	0.1872	-0.0002981	0.036956	-0.0001731	0.0000255	0.921

Appendix B.5. Regression Coefficients - Growth Rate of Total Biomass

Response Variable	b_0	b_1	b_2	b_3	b_4	b_5	r^2
Growth Rate A	4.5147	0.0641474	-0.0002636	0.0187522	0.0000392	0.000498	0.578
Growth Rate AB	3.8038	0.0976907	-0.0000301	0.021073	-0.0000139	0.0002311	0.960

Appendix B.6. Regression Coefficients - Phenological Development

DAP to 50% Tas	79.7410	-0.0975401	0.0002199	-0.42302	0.0000866	0.0000784	0.866
DAP to 50% Sil	93.1187	-0.2175	0.0006093	-0.0465113	0.0001093	0.0000275	0.946
D bet 50% Tas + Sil	13.3776	-0.1199	0.0003894	-0.0042093	0.000227	-0.000051	0.831
Crop Greenness	0.9980	0.132888	-0.0000222	-0.0006697	-0.0000055	0.000002	0.850
Crop Brownness	1.0103	0.0087821	-0.0000263	0.0014012	0.000007	0.0000088	0.670
Dead Leaf Count	14.2012	-0.0629208	0.0001632	0.0142221	-0.0000368	0.0000314	0.517
DAP to Physiol Maturity	147.7932	-0.0394041	-0.0000858	-0.0036898	-0.0000358	-0.0000176	0.604

Appendix B.7. Regression Coefficients - Ear Leaf Analysis

N	1.1687	0.0082841	-0.0000187	-0.0014159	0.000005	-0.0000056	0.862
Ca	0.4023	0.0003797	0.0000028	-0.0004489	0.0000031	-0.0000027	0.685
S	0.0533995	0.0004842	-0.0000013	-0.0001491	0.0000007	-0.0000003	0.665
Mn	96.1271	-0.1764	0.002195	0.0022142	0.0000617	-0.0006765	0.746
Fe	94.5093	0.0968551	0.0005168	-0.088592	0.0005668	-0.0009235	0.770

APPENDIX C. SOIL PROFILE ANALYSIS*

Rep	D	Truog P	KCl Extract NH4	KCl Extract NO3	Org. Carb.	Tot. N	pH H2O	pH KCl	Cations Ca	Cations Mg	Cations Na	Cations K
		mg/kg	.. mg/kg..		%	%			.....	cmol	(+)/kg.	....
1	1	15.19	9.16	12.14	0.98	0.07	4.9	4.8	4.74	1.25	0.23	0.76
1	2	20.04	4.01	0.00	1.19	0.14	5.1	4.9	5.02	1.44	0.16	1.00
1	3	1.05	1.74	0.00	0.69	0.08	5.3	5.2	3.79	1.08	0.15	0.36
1	4	1.05	5.51	0.00	0.54	0.08	5.4	5.2	3.75	1.37	0.15	0.29
1	5	2.74	2.49	0.00	0.65	0.08	5.5	5.4	4.02	1.51	0.15	0.31
1	6	2.53	0.00	0.00	0.34	0.05	5.6	5.7	3.93	1.77	0.16	0.16
1	7	1.05	0.00	0.00	0.30	0.05	5.7	5.8	3.71	1.88	0.18	0.12
2	1	11.18	6.47	2.49	1.06	0.12	5.4	5.3	4.42	1.09	0.20	0.65
2	2	8.02	2.24	0.00	1.10	0.12	5.5	5.3	4.34	1.14	0.13	0.71
2	3	2.11	3.97	0.00	0.61	0.07	5.8	5.7	4.11	1.00	0.13	0.33
2	4	0.85	5.43	0.00	0.60	0.07	5.8	5.6	3.70	1.19	0.15	0.24
2	5	0.84	0.00	0.00	0.60	0.06	5.8	5.7	3.63	1.24	0.17	0.31
2	6	0.42	0.00	0.00	0.57	0.05	5.9	5.7	3.54	1.56	0.19	0.14
2	7	0.00	0.00	0.00	0.63	0.06	5.9	5.7	3.56	1.94	0.24	0.13
3	1	29.32	3.22	8.67	1.39	0.14	5.3	4.9	3.54	1.02	0.27	0.54
3	2	12.02	6.20	0.00	1.06	0.11	5.4	4.8	3.24	0.83	0.13	0.46
3	3	1.90	6.45	0.00	0.53	0.06	5.5	5.1	3.36	1.05	0.12	0.32
3	4	1.22	0.00	0.00	0.53	0.06	5.6	5.3	3.24	1.30	0.12	0.27
3	5	1.27	0.00	0.00	0.42	0.06	5.7	5.4	3.04	1.39	0.15	0.25
3	6	0.42	0.00	0.00	0.38	0.05	5.8	5.5	2.99	1.46	0.17	0.15
3	7	0.42	0.00	0.00	0.30	0.04	5.9	5.6	2.88	1.56	0.18	0.14

* D = depth (1=0-15cm; 2=15-30cm; 3=30-45cm; 4=45-60cm; 5=60-75cm; 7=90-105cm.) Truog P=Modified Truog P.

APPENDIX D. DATA FOR INDIVIDUAL PLOTS.

D.4. Yield Variables*

Rep	T	DL	GRN	BRN	DPM	GY	SY	EL	HKW	ELW
					days	...Mg/ha..		cm	g	g
1	1	10	1.0	1.0	154	1.17	2.07	73.0	19.07	12.5
2	1	13	1.0	1.0	151	0.82	2.81	67.0	21.55	13.1
3	1	10	1.0	1.5	145	0.90	2.72	79.5	22.17	10.5
1	2	14	1.0	1.0	153	0.76	2.67	74.5	19.38	13.9
2	2	18	1.0	1.0	151	1.46	3.58	86.5	18.45	16.3
3	2	12	1.0	1.5	145	0.58	2.49	71.0	22.63	12.1
1	3	16	1.0	1.0	145	2.10	3.09	94.5	23.25	13.3
2	3	15	1.0	1.5	145	0.40	2.42	64.0	19.53	10.5
3	3	12	1.0	1.5	146	0.94	2.92	71.0	21.24	12.6
1	4	18	1.0	1.5	149	1.92	3.37	89.5	17.67	15.8
2	4	16	1.0	1.5	144	2.56	4.57	98.0	21.39	15.2
3	4	14	1.0	1.5	145	3.19	3.65	108.0	21.24	13.6
1	5	13	2.0	1.0	142	5.97	5.14	129.5	22.17	26.3
2	5	14	1.5	1.0	144	3.95	3.98	112.5	19.69	22.7
3	5	12	1.5	1.5	144	5.13	5.24	125.0	22.79	21.9
1	6	17	1.5	2.0	143	4.75	5.02	118.0	20.93	24.7
2	6	10	1.5	1.5	147	6.72	7.30	143.5	20.15	25.6
3	6	11	1.5	1.5	146	5.14	6.11	119.0	20.93	20.2
1	7	9	2.0	1.5	143	8.87	6.93	153.5	21.24	27.6
2	7	9	2.0	2.0	140	9.05	10.05	150.0	20.00	28.1
3	7	9	2.0	1.5	143	8.61	6.39	158.0	20.46	24.3
1	8	10	2.0	1.5	143	10.18	8.64	161.5	22.32	34.8
2	8	11	2.0	2.0	143	9.00	7.46	144.5	20.15	40.0
3	8	9	2.0	2.0	143	7.48	11.45	145.5	21.55	28.1
1	9	11	2.0	3.0	143	8.36	8.20	159.0	22.17	27.9
2	9	14	2.0	2.5	133	6.59	7.45	138.5	20.00	31.5
3	9	10	2.0	2.5	143	7.21	6.92	141.0	21.86	29.7
1	10	8	3.0	2.0	133	9.61	7.00	159.5	22.48	35.3
2	10	10	3.0	1.5	143	11.39	8.78	166.0	22.94	37.1
3	10	10	3.0	2.0	143	11.64	8.14	173.5	23.87	34.8
1	11	14	2.0	2.5	143	10.09	9.94	168.5	21.24	37.1
2	11	12	2.5	2.5	132	11.40	9.57	160.5	24.80	34.4
3	11	9	3.0	2.5	145	10.20	6.90	169.5	22.79	33.1
1	12	13	2.0	1.5	145	11.15	7.61	170.0	23.10	35.6
2	12	3	3.0	1.5	134	11.83	11.81	175.5	23.10	43.2
3	12	8	3.0	2.0	131	11.23	8.93	178.0	23.41	36.2
1	13	9	3.0	2.0	133	11.92	10.71	169.0	24.34	37.7
2	13	13	2.0	2.5	140	11.32		177.5	23.80	44.9
3	13	9	3.0	2.5	133	11.21	8.49	174.0	22.01	42.6
1	14	13	2.5	2.0	133	11.49	9.82	181.5	22.63	37.9
2	14	8	3.0	3.0	132	12.58	8.00	170.5	25.73	39.0
3	14	9	3.0	2.0	133	12.39	9.59	200.5	23.87	44.2

D.5. Tissue Analysis con't

1	15	1.65	0.13	1.52	0.45	0.14	0.08	1.43	0.11	146	117
2	15	1.73	0.15	1.52	0.54	0.16	0.10	1.18	0.09	51	131
3	15	1.61	0.13	1.41	0.45	0.17	0.08	1.15	0.10	51	116
1	16	2.01	0.13	1.48	0.62	0.15	0.09	1.14	0.11	133	149
2	16	1.72	0.14	1.60	0.50	0.16	0.09	1.14	0.12	53	116
3	16	1.75	0.15	1.59	0.56	0.17	0.08	0.92	0.12	309	139
1	17	1.79	0.12	1.51	0.46	0.14	0.08	1.56	0.11	80	141
2	17	1.51	0.12	1.42	0.49	0.17	0.08	0.85	0.08	153	99
3	17	1.50	0.13	1.46	0.44	0.14	0.07	1.03	0.10	41	121
1	18	2.55	0.21	1.86	0.53	0.17	0.11	1.14	0.21	57	163
2	18	2.39	0.21	1.76	0.56	0.19	0.12	0.83	0.20	43	136
3	18	2.20	0.21	1.66	0.54	0.23	0.11	0.92	0.18	117	125

* T=treatment; LN=leaf N; LP=leaf P; LK=leaf K; LCa=leaf Ca; LMg=leaf Mg; LS=leaf S; LSi=leaf Si; LCl=leaf Cl; LAl=leaf Al; LMn=leaf Mn.

APPENDIX D. DATA FOR INDIVIDUAL PLOTS.

D.5. Tissue Analysis*

Rep	T	LN	LP	LK	LCa	LMg	LS	LSi	LCl	LAl	LMn
		....	....	....	....	%	....	....	....	mg/kg	
1	1	1.29	0.14	1.62	0.45	0.17	0.06	0.98	0.16	116	83
2	1	1.12	0.15	1.59	0.39	0.21	0.05	0.84	0.14	123	83
3	1	1.16	0.22	1.38	0.40	0.21	0.06	1.38	0.11	59	96
1	2	1.12	0.13	1.71	0.34	0.27	0.05	0.92	0.14	64	94
2	2	1.01	0.18	1.42	0.38	0.18	0.04	1.11	0.10	52	87
3	2	1.15	0.26	1.49	0.43	0.27	0.06	1.33	0.14	53	121
1	3	1.12	0.20	1.34	0.39	0.20	0.05	1.53	0.10	119	95
2	3	1.26	0.20	1.67	0.49	0.19	0.07	1.02	0.14	59	89
3	3	1.21	0.20	1.33	0.43	0.21	0.05	1.56	0.10	54	97
1	4	0.98	0.20	1.38	0.41	0.22	0.04	1.26	0.12	65	94
2	4	1.03	0.22	1.47	0.38	0.20	0.04	1.28	0.10	64	86
3	4	1.21	0.22	1.36	0.42	0.20	0.06	1.45	0.12	53	105
1	5	1.64	0.14	1.49	0.43	0.15	0.08	1.38	0.13	82	99
2	5	1.27	0.16	1.44	0.35	0.16	0.06	1.03	0.10	55	83
3	5	1.36	0.17	1.38	0.41	0.17	0.07	1.07	0.13	47	89
1	6	1.41	0.15	1.39	0.41	0.14	0.06	1.25	0.10	82	92
2	6	1.32	0.19	1.43	0.43	0.18	0.06	1.40	0.09	51	92
3	6	1.33	0.17	1.30	0.41	0.18	0.06	1.23	0.09	71	100
1	7	1.98	0.17	1.53	0.51	0.15	0.09	1.45	0.13	55	100
2	7	1.87	0.17	1.58	0.46	0.15	0.09	1.06	0.17	47	79
3	7	1.72	0.17	1.37	0.44	0.17	0.08	0.97	0.12	132	93
1	8	1.61	0.16	1.48	0.44	0.13	0.07	1.31	0.10	46	102
2	8	1.87	0.17	1.42	0.49	0.15	0.08	1.20	0.12	49	95
3	8	1.67	0.17	1.34	0.40	0.18	0.08	1.14	0.10	205	120
1	9	1.69	0.13	1.44	0.46	0.14	0.08	1.03	0.10	47	85
2	9	1.58	0.15	1.45	0.43	0.15	0.07	1.05	0.10	143	81
3	9	1.44	0.31	1.24	0.49	0.20	0.13	1.10	0.09	155	112
1	10	1.93	0.15	1.48	0.45	0.15	0.09	1.40	0.10	52	111
2	10	2.00	0.18	1.39	0.47	0.16	0.09	1.34	0.10	40	109
3	10	1.96	0.17	1.37	0.45	0.17	0.09	1.31	0.10	47	109
1	11	1.53	0.14	1.38	0.44	0.14	0.07	1.39	0.10	120	98
2	11	1.91	0.17	1.44	0.48	0.16	0.09	0.98	0.11	167	91
3	11	1.67	0.21	1.49	0.44	0.36	0.08	1.26	0.09	47	112
1	12	2.13	0.18	1.71	0.55	0.23	0.10	1.53	0.18	136	144
2	12	2.16	0.20	1.51	0.66	0.29	0.12	1.44	0.16	255	175
3	12	1.96	0.19	1.43	0.65	0.24	0.09	1.68	0.12	123	149
1	13	1.98	0.17	1.73	0.50	0.16	0.09	1.67	0.14	123	132
2	13	1.61	0.15	1.50	0.48	0.17	0.08	1.17	0.11	52	127
3	13	1.68	0.13	1.49	0.48	0.18	0.08	1.32	0.11	65	138
1	14	1.87	0.14	1.58	0.52	0.15	0.08	1.51	0.11	210	132
2	14	1.95	0.16	1.62	0.54	0.19	0.09	1.04	0.12	55	119
3	14	1.80	0.15	1.56	0.53	0.18	0.09	1.18	0.10	49	124

D.4 Yield Variables con't

1	15	10	3.0	2.5	132	11.55		170.5	23.10	42.7
2	15	8	2.5	2.5	132	11.95	7.50	160.5	23.10	51.4
3	15	9	2.5	2.5	134	11.54	12.24	175.5	23.72	45.5
1	16	11	3.0	2.5	134	10.27	9.36	174.0	20.93	37.4
2	16	11	3.0	2.5	133	11.38	12.45	181.0	24.65	52.3
3	16	11	3.0	2.5	133	10.57	8.62	176.5	23.10	44.6
1	17	13	2.0	2.5	132	13.09		143.5	23.10	36.1
2	17	15	3.0	3.0	132	10.51	9.95	138.5	21.39	34.8
3	17	13	3.0	2.5	132	11.33	9.04	143.0	22.48	33.8
1	18	6	3.0	2.5	129	15.08	14.09	196.5	26.35	55.2
2	18	5	3.0	2.5	128	13.51	10.85	185.5	25.11	50.9
3	18	2	3.0	2.0	130	13.86	12.69	186.0	27.44	54.8

* T=treatment; DL= number of dead leaves; GRN=crop greenness; BRN=crop brownness; DPM=number of days to physiological maturity; GY=grain yield; SY=stover yield; EL=filled ear length/10 ears; HKW=hundred kernel weight; ELW= ear leaf weight.

APPENDIX D. DATA FOR INDIVIDUAL PLOTS.

D.3. Phenological Measurements*

Rep	Trt	Ht.A	Ht.B	Ht.C	Bio. A	Bio. B	Bio. CS	Bio. CE	TAS	SIL	DIF
		.........cm.........			...........g..........				.....days....		
1	1	17.9	53.9	136.2	3.8				85	95	10
2	1	22.3	70.9	162.1	10.0				79	93	14
3	1	23.1	77.6	175.3	14.1				75	92	17
1	2	17.5	58.6	127.8	4.7	181	285	168	85	96	11
2	2	21.8	77.7	162.1	17.9				76	92	16
3	2	23.0	73.9	165.7	8.5	167	282	63	78	93	15
1	3	25.8	89.6	188.1	35.2				76	88	12
2	3	25.2	78.1	166.5	18.8				78	93	15
3	3	27.6	82.4	173.0	19.4				76	92	16
1	4	23.3	91.8	181.7	26.7	431			75	91	16
2	4	27.8	92.5	172.3	34.4				76	88	12
3	4	28.3	89.5	207.3	25.0	347			74	85	11
1	5	27.3	126.9	240.5	55.5	639	700	484	72	78	6
2	5	28.2	115.5	209.6	27.5				76	82	6
3	5	29.5	119.4	225.5	28.7	507	549	523	74	78	4
1	6	33.5	142.7	235.5	51.5	719	772	635	70	78	8
2	6	27.3	128.1	247.6	24.1				71	77	6
3	6	39.9	153.3	251.5	55.3	628	747	569	70	78	8
1	7	25.1	143.3	262.5	30.7				71	76	5
2	7	27.7	163.3	284.4	9.3				72	78	6
3	7	28.0	134.8	240.0	37.6				73	78	5
1	8	25.0	145.2	256.3	68.5	875	883	733	68	75	7
2	8	34.1	178.3	269.7	23.7				71	75	4
3	8	37.4	155.8	244.9	32.2	869	618	512	70	76	6
1	9	33.4	155.9	256.2	83.2				69	74	5
2	9	37.9	166.7	256.1	86.2				69	72	3
3	9	34.2	165.0	252.6	42.6				69	76	7
1	10	29.5	173.2	282.1	19.7				70	74	4
2	10	33.4	191.4	283.1	47.5				68	74	6
3	10	36.5	217.0	311.9	24.6				69	72	3
1	11	32.9	184.3	278.8	62.3				69	72	3
2	11	41.7	183.0	299.6	139.2				68	70	2
3	11	50.0	219.5	301.2	57.2				67	71	4
1	12	26.1	164.9	271.9	25.2	1136	907	992	69	72	3
2	12	27.0	175.2	293.2	29.3				70	75	5
3	12	31.6	187.0	277.0	25.7	1036	1032	908	68	75	7
1	13	31.1	215.0	314.3	64.4	1259			68	71	3
2	13	38.2	188.3	302.8	56.3	1403			66	70	4
3	13	40.0	202.4	293.0	39.2	1118			67	70	3
1	14	31.4	193.5	296.9	92.6	1713	1297	932	68	71	3
2	14	41.5	224.2	330.9	155.6	1733			65	70	5
3	14	43.8	201.8	280.8	46.9	1273	1015	1126	68	68	0

D.3. Phenological Measurements con't

1	15	35.5	216.0	307.1	83.8	1301			65	68	3
2	15	53.1	234.8	309.2	105.7	1592			65	68	3
3	15	48.4	234.0	312.6	102.5	1411			65	68	3
1	16	35.0	201.5	297.9	141.5	1326			68	71	3
2	16	39.2	219.0	303.8	74.6	1267			65	68	3
3	16	44.5	222.7	313.3	90.2				65	68	3
1	17	34.0	211.3	296.9	95.2	1174	1074	823	64	68	4
2	17	44.9	206.7	290.8	64.7	953			67	70	3
3	17	48.3	205.1	303.4	137.8		857	715	64	68	4
1	18	35.0	258.6	335.2	127.3	1783	1456	1293	61	64	3
2	18	48.6	267.0	331.7	129.5	1665			62	65	3
3	18	62.6	276.5	310.1	166.9	1620	1559	1548	61	64	3

* Ht.A at 24 DAP; Ht.B at 57 DAP; Ht.C at 119 DAP; Bio.A at 31 DAP; Bio.B at 73 DAP; Bio.CS=Stover biomass at the dough stage; Bio.CE=Ear biomass at the dough stage; TAS=days to 50% tasselling; SIL=days to 50% silking; DIF=days between tasselling and silking.

APPENDIX D. DATA FOR INDIVIDUAL PLOTS

D.2. Post Harvest Soil Analysis*

		Truog	KCl Extract		pH		Cations					
Rep	Trt	P	NH4	NO3	H2O	KCl	Cu	Zn	Ca	Mg	Na	K
		mg/kg	mg/kg				mg/kg		cmol (+)/kg			
1	1	20.49	0.00	0.00	5.9	5.3	0.36	0.07	5.12	2.04	0.23	0.68
2	1	17.83	3.51	0.00	5.9	5.2	0.29	0.05	5.00	2.18	0.18	0.91
3	1	33.40	5.21	0.00	5.9	5.1	0.34	0.03	4.45	1.75	0.20	0.72
1	2	13.11	0.00	0.00	5.8	5.2	0.35	0.12	4.82	1.58	0.22	0.98
2	2	36.48	6.68	0.00	5.9	5.2	0.52	0.30	5.82	1.94	0.22	1.14
3	2	34.22	0.00	0.00	5.9	5.0	0.38	0.06	4.26	1.76	0.18	0.69
1	3	56.56	3.96	2.48	5.5	5.0	0.72	0.52	6.27	1.31	0.30	1.40
2	3	37.50	6.04	0.00	5.8	5.3	0.30	0.18	4.59	1.99	0.18	1.04
3	3	79.30	0.00	0.00	5.8	4.9	0.40	0.12	4.87	1.36	0.24	0.67
1	4	87.30	0.00	0.00	5.7	5.2	0.56	0.29	6.06	2.19	0.20	1.00
2	4	67.01	0.00	1.25	5.8	5.2	0.52	0.24	5.69	1.84	0.23	1.01
3	4	67.01	8.19	0.00	5.6	5.0	0.34	0.16	5.20	1.67	0.24	0.89
1	5	31.56	4.49	0.00	5.6	5.0	0.55	0.36	5.15	1.83	0.22	1.10
2	5	52.46	6.27	0.00	5.9	5.3	0.48	0.29	5.43	2.86	0.24	0.94
3	5	48.98	2.50	0.00	5.7	5.1	0.37	0.20	4.79	1.58	0.26	1.03
1	6	59.43	4.24	0.00	5.7	5.2	0.49	0.34	5.87	1.83	0.21	1.28
2	6	67.42	0.00	5.04	5.8	5.3	0.43	0.30	5.47	2.53	0.21	0.98
3	6	83.20	3.01	0.00	5.9	5.1	0.41	0.28	6.03	1.75	0.24	1.17
1	7	24.59	5.96	3.23	5.6	5.0	0.73	0.45	5.74	2.02	0.21	1.26
2	7	26.82	9.05	0.00	5.8	5.3	0.32	0.16	4.69	2.14	0.18	1.29
3	7	26.43	3.23	0.00	5.8	5.1	0.32	0.18	4.86	1.32	0.20	0.84
1	8	50.41	5.76	0.00	5.7	5.2	0.57	0.33	5.86	2.04	0.21	1.44
2	8	51.02	5.74	4.49	5.8	5.3	0.46	0.25	5.17	2.14	0.23	1.12
3	8	52.87	3.00	0.00	5.8	5.0	0.37	0.07	4.49	1.96	0.21	0.81
1	9	95.70	0.00	0.00	5.8	5.2	0.34	0.15	5.52	1.88	0.20	1.13
2	9	63.73	7.95	0.00	5.8	5.3	0.32	0.14	5.08	2.57	0.20	0.95
3	9	110.45	1.99	0.00	5.8	4.9	0.38	0.10	5.08	1.28	0.25	0.49
1	10	20.08	5.70	0.00	5.7	5.2	0.44	0.22	5.26	1.77	0.20	1.16
2	10	40.16	1.74	4.22	5.8	5.3	0.38	0.22	4.79	2.16	0.22	1.20
3	10	44.67	0.00	0.00	5.7	5.0	0.34	0.16	4.09	1.79	0.18	1.27
1	11	56.97	6.94	2.48	5.8	5.2	0.53	0.32	5.90	2.24	0.21	1.15
2	11	63.12	3.23	6.03	5.8	5.2	0.32	0.18	4.26	1.92	0.17	1.16
3	11	67.42	4.22	0.00	5.9	5.1	0.37	0.18	4.85	2.08	0.18	1.28
1	12	21.72	0.00	2.48	5.4	4.9	0.68	0.66	5.62	1.81	0.23	1.04
2	12	36.27	3.20	0.00	5.8	5.2	0.38	0.25	4.95	2.15	0.20	0.93
3	12	31.15	5.94	0.00	5.9	5.1	0.40	0.16	5.42	1.57	0.24	0.66
1	13	56.97	5.01	0.00	5.7	5.1	0.65	0.45	5.92	1.98	0.19	1.67
2	13	47.54	5.24	2.99	5.8	5.3	0.44	0.25	4.94	2.19	0.20	1.26
3	13	63.12	7.44	0.00	5.9	5.0	0.39	0.05	5.65	1.64	0.18	0.87
1	14	65.98	5.46	0.00	5.8	5.1	0.58	0.42	5.84	1.96	0.22	1.30
2	14	74.18	0.00	0.00	5.8	5.2	0.34	0.18	4.58	2.08	0.15	1.16
3	14	84.63	0.00	5.22	5.7	5.2	0.36	0.22	5.02	2.30	0.22	1.00

D.2. Post Harvest Analysis con't

1	15	69.47	4.51	4.26	5.6	4.9	0.62	0.43	5.20	2.19	0.18	1.40
2	15	77.66	0.00	0.00	5.7	5.2	0.43	0.20	5.47	2.07	0.20	1.50
3	15	83.81	0.00	2.73	5.6	5.1	0.34	0.04	4.60	2.21	0.17	1.21
1	16	45.29	5.46	0.00	5.7	5.2	0.36	0.13	5.37	1.65	0.20	1.45
2	16	42.62	0.00	0.00	5.9	5.3	0.30	0.09	4.70	2.15	0.20	1.21
3	16	92.29	0.00	0.00	5.7	5.0	0.33	0.16	4.28	1.97	0.17	1.02
1	17	64.34	3.50	0.00	5.4	5.0	0.62	0.49	5.40	2.17	0.20	1.46
2	17	56.15	9.94	0.00	5.8	5.2	0.36	0.25	5.51	1.89	0.19	1.82
3	17	110.66	3.50	0.00	5.7	5.2	0.35	0.38	4.53	2.12	0.15	1.33
1	18	108.61	6.25	12.51	5.5	5.1	0.69	0.57	7.78	2.12	0.18	1.86
2	18	111.27	11.21	11.96	5.7	5.4	0.35	0.28	7.38	2.35	0.16	1.15
3	18	209.00	0.00	22.49	5.7	5.3	0.41	0.34	9.63	1.85	0.24	1.65

* Truog P = Modified Truog P.

APPENDIX D. DATA FOR INDIVIDUAL PLOTS.

D.1. Preplant Soil Analysis*

		Truog	KCl Extract		pH		Cations			
Rep	Trt	P	NH4	NO3	H2O	KCl	Ca	Mg	Na	K
		mg kg-1	mg kg-1				cmol(+) kg-1			
1	1	13.48	9.52	0.00	5.75	5.18	4.77	1.13	0.19	0.65
1	2	19.25	4.81	3.01	5.62	5.09	4.78	1.09	0.20	0.61
1	3	32.76	13.28	4.03	5.15	4.83	6.10	1.25	0.16	1.06
1	4	40.65	12.10	0.00	5.75	5.10	5.81	1.46	0.17	1.06
1	5	16.74	12.09	5.44	5.29	4.87	4.94	1.37	0.17	0.85
1	6	15.65	8.82	0.00	5.94	5.26	6.35	1.32	0.17	1.00
1	7	26.74	15.38	10.84	5.85	5.07	5.78	1.40	0.16	1.26
1	8	34.78	17.56	0.00	5.81	5.12	5.95	1.40	0.17	1.10
1	9	16.30	8.02	0.00	5.76	5.05	5.07	1.25	0.17	0.73
1	10	13.04	15.13	0.00	5.85	5.21	5.75	1.21	0.17	0.76
1	11	37.17	13.31	0.00	5.70	5.11	5.86	1.34	0.17	1.11
1	12	35.98	17.16	9.08	5.15	4.87	6.08	1.34	0.19	1.11
1	13	38.91	16.59	5.78	5.68	5.12	6.12	1.52	0.17	1.46
1	14	29.29	17.34	5.65	5.48	5.08	5.90	1.28	0.22	0.92
1	15	28.66	17.16	7.07	5.28	4.83	4.77	1.35	0.18	0.98
1	16	12.17	15.52	0.00	5.90	5.22	5.90	1.30	0.20	0.80
1	17	28.70	18.10	5.53	5.95	4.94	4.96	1.38	0.17	1.11
1	18	30.43	13.61	6.81	5.81	5.11	6.04	1.37	0.16	1.34
2	1	18.26	15.46	3.69	5.70	5.06	4.71	1.31	0.16	0.82
2	2	46.65	13.47	5.83	5.61	5.11	5.65	1.32	0.18	1.03
2	3	22.18	7.20	6.40	5.55	5.07	4.49	1.28	0.18	0.77
2	4	43.32	19.67	0.00	5.34	4.98	5.60	1.28	0.16	1.01
2	5	35.13	19.05	0.00	5.49	5.02	5.66	1.04	0.16	1.16
2	6	43.10	17.99	5.20	5.54	5.12	5.67	1.08	0.16	1.15
2	7	21.13	9.58	0.00	5.55	5.19	4.44	1.13	0.19	0.76
2	8	33.68	15.67	6.83	5.57	5.06	5.03	1.08	0.18	0.91
2	9	16.81	15.27	0.00	5.57	5.12	4.69	1.18	0.16	0.75
2	10	38.70	15.98	6.19	5.54	5.17	5.63	1.04	0.17	0.76
2	11	39.22	19.55	2.99	5.45	4.93	4.29	0.94	0.14	0.88
2	12	34.35	11.74	1.75	5.75	5.14	6.25	1.18	0.15	0.86
2	13	38.70	17.80	0.00	5.48	5.05	5.32	1.40	0.16	1.14
2	14	29.31	15.01	7.00	5.53	5.01	4.20	1.07	0.15	0.78
2	15	34.78	12.77	4.01	5.55	5.02	5.62	1.08	0.15	0.98
2	16	17.83	11.26	0.00	5.63	5.10	4.63	1.16	0.15	0.79
2	17	24.13	17.53	0.00	5.76	5.08	5.01	1.36	0.17	0.92
2	18	23.85	11.20	6.80	5.55	5.13	4.24	1.03	0.17	0.72

D.l. Preplant Soil Analysis con't

3	1	41.16	19.33	7.38	5.34	4.82	4.57	0.97	0.16	0.52
3	2	31.74	14.94	4.73	5.28	4.81	4.32	1.07	0.16	0.60
3	3	39.13	8.72	4.73	5.58	4.96	5.44	1.23	0.17	0.42
3	4	33.48	16.44	2.99	5.55	4.99	4.86	1.21	0.16	0.88
3	5	40.40	23.10	6.37	5.45	5.01	5.22	1.09	0.16	0.88
3	6	39.13	13.73	7.99	5.64	5.06	5.68	1.38	0.15	0.75
3	7	34.94	12.74	3.88	5.59	5.15	4.88	1.01	0.17	0.55
3	8	35.77	17.63	7.01	5.43	4.89	4.24	1.03	0.18	0.35
3	9	34.31	16.01	0.00	5.48	4.98	5.21	1.15	0.19	0.32
3	10	35.13	18.17	7.59	5.37	4.77	3.92	0.88	0.13	0.65
3	11	40.09	22.37	9.98	5.38	4.79	4.28	0.98	0.14	0.74
3	12	42.24	13.18	3.60	5.55	5.00	6.02	1.21	0.18	0.50
3	13	48.49	13.97	7.98	5.51	4.81	4.46	0.96	0.16	0.47
3	14	39.75	9.80	9.00	5.57	5.08	4.85	1.06	0.16	0.73
3	15	32.84	15.13	0.00	5.50	4.96	3.88	0.89	0.15	0.58
3	16	43.10	9.19	11.58	5.46	4.87	4.13	0.96	0.17	0.65
3	17	45.69	19.35	1.02	5.45	4.85	3.79	0.86	0.14	0.70
3	18	33.70	16.23	2.99	5.59	5.04	6.10	1.30	0.16	0.88

* Truog P=Modified Truog P.

APPENDIX E. METEOROLOGICAL DATA.

APRIL

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.01			781	29
2	0.14			679	17
3	0.00			669	83
4	0.00			990	21
5	0.00			1035	25
6	0.00			900	19
7	0.00			816	17
8	0.02			754	95
9	0.00	73	59	699	14
10	0.00	78	59	978	15
11					
12		81	58	2086	50
13	0.00	78	62	1063	25
14	0.00	84	66	1357	27
15	0.00	80	65	862	105
16	0.05	81	63	1125	30
17	0.04	74	65	704	25
18	0.00	75	65	699	36
19	0.00	79	64	1166	25
20	0.06	80	66	1101	30
21	0.00	78	64	1431	40
22	0.62	79	65	434	67
23	0.02	79	64	1109	81
24	0.00	78	64	1045	33
25	0.01	80	67	839	23
26	0.02	77	64	542	25
27	0.00	81	64	1239	15
28	0.00	80	64	1003	
29	0.00	78	65	1927	20
30	0.00	79	62	815	94

[1] Solar Rad=Solar Radiation (langley/day x 0.468)
[2] Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

APPENDIX E con't

MAY

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.20	79	66	1046	14
2	0.05	71	62	482	15
3	0.00	79	68	1265	78
4	0.00	84	66	1379	24
5	0.00	82	65	1105	30
6	0.32	83	65	971	100
7	0.33	76	64	584	15
8	0.09	79	65	871	15
9	0.00	78	64	1166	70
19	0.00	80	66	1325	65
11	0.08	79	66	916	16
12	0.01	78	66	1029	20
13	0.12	78	65	1206	100
14	0.07	78	65	1201	46
15	0.08	80	65	1229	51
16	0.08	75	65	742	26
17	0.57	74	64	716	28
18	0.01	74	63	809	15
19	0.12	74	64	1161	22
20	0.13	68	60	348	70
21	0.05	71	60	543	26
22	0.00	75	64	596	33
23	0.26	77	67	377	30
24	0.13	70	65	286	16
25	0.00	84	68	1219	17
26	0.00	84	69	1374	25
27	0.00	84	69	1381	47
28	0.00	80	65	1238	30
29	0.03	81	66	1230	120
30	0.00	79	67	967	40
31	0.00	77	67	759	42

[1] Solar Rad=Solar Radiation (langley/day x 0.468)
[2] Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

APPENDIX E con't

<u>June</u>

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.00	79	66	1047	15
2	0.00	81	72	1066	
3	0.00	83	70	1243	35
4	0.00	83	70	973	110
5	0.00	83	65	1328	61
6	0.00	83	66	1200	55
7	0.00	84	68	1365	30
8	0.01	84	68	929	20
9	0.00	85	68	1236	27
10		86	70	903	50
11	0.00	86	68	861	
12	0.00	83	69	1053	123
13	0.07	83	68	1187	56
14	0.00	82	68	1263	62
15	0.00	84	69	750	12
16	0.00	80	63	692	15
17	0.00	83	68	1318	110
18	0.00	86	69	775	40
19	0.00	84	68		50
20		84	68	1104	50
21					
22	0.00	84	70	1542	
23	0.00	84	72		
24	0.00	84	69		115
25	0.30	82	68	218	43
26	0.15	79	68	656	20
27	0.11	78	64	615	41
28	1.45	79	67	699	20
29	0.00	83	68	1404	10
30	0.00	83	68	1423	35

[1] Solar Rad=Solar Radiation (langley/day x 0.468)
[2] Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

APPENDIX E con't

July

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.01	82	72	818	57
2		81	60	913	35
3	0.00	83	72	1152	60
4	0.00	83	67	1117	15
5	0.00	86	67	1378	46
6	0.00	85	70	1233	48
7	0.00	85	70	997	53
8	0.00	83	72	1056	92
9	0.00	84	70	1127	55
10	0.00	85	70	1296	72
11	0.00	86	69	1320	78
12	0.00	85	63	931	48
13	0.00	79	68	1388	44
14	0.00	84	70	860	25
15	0.00	87	67	918	67
16	0.00	86	70	1049	76
17	0.01	86	70	925	44
18	0.19	86	72	611	35
19	0.00	85	72	1183	55
20	0.00	85	70	1225	22
21	0.01	84	69	1020	38
22		84	72	1202	56
23	0.00	84	70	1115	52
24	0.04	84	72	1114	48
25	0.13	85	70	1432	83
26	0.00	84	72	1407	87
27	0.00	85	73	1690	42
28	0.01	82	71	1154	22
29	0.02	81	70	97	94
30	0.04	84	71	39	67
31	0.39	81	71	60	45

[1] Solar Rad=Solar Radiation (langley/day x 0.468)
[2] Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

APPENDIX E con't

August

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.45	82	62	47	25
2	0.02	85	72	48	18
3	0.02	82	72	68	45
4	0.06	80	72	54	90
5	0.01	82	70	30	15
6	0.00	82	70	41	16
7	0.00	80	69	44	20
8	0.00	84	69	55	60
9	0.00	81	72	50	
10	0.00	83	72	67	40
11	0.00	84	66	1426	95
12	0.00	87	72	1077	21
13	0.02	85	71	1225	140
14	0.00	84	68	1069	26
15	0.00	84	68	969	50
16	0.01	85	68	923	32
17	0.00	84	69	1066	22
18	0.10	82	66	640	
19	0.00	83	67	2088	100
20	0.00	87	72	1322	45
21	0.00	86	71	1317	40
22	0.00	84	70	1108	57
23	0.00	83	69	1057	43
24	0.00	83	70	999	55
25	0.02	83	71	841	31
26	0.00	81	69	669	40
27	0.00	87	72	1205	50
28	0.00	85	72	1154	51
29	0.00	85	70	1190	50
30	0.05	83	72	1049	45
31					

[1] Solar Rad=Solar Radiation (langley/day x 0.468)
[2] Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

APPENDIX E con't

September

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.00	84	71	1995	55
2	0.00	85	71	1351	65
3	0.00	85	72	2503	62
4	0.00	85	72	1230	86
5	0.00	86	74	1260	50
6	0.00	85	70	884	40
7	0.00	85	71	1094	43
8	0.00	80	72	903	35
9	0.00	81	64	687	40
10	0.00	82	66	858	35
11	0.06	82	65	1142	45
12	0.10	81	64	855	25
13	0.03	82	64	837	35
14	0.22	81	66	675	24
15	0.00	84	65	764	30
16	0.75	85	74	789	15
17	0.01	86	72	629	45
18	0.00	83	70	873	40
19	0.02	85	71	1046	44
20	0.01	82	70	684	30
21	0.00	83	70	1185	44
22	0.05	82	71	1139	44
23	0.02	83	71	894	34
24	0.88	84	70	816	15
25	0.60	81	71	685	12
26	0.10	81	73	838	43
27	0.79	79	71	434	6
28	0.01	81	71	843	34
29	0.02	82	70	1184	45
30	0.02	81	72	905	33

[1] Solar Rad=Solar Radiation (langley/day x 0.468)
[2] Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

APPENDIX E CON'T

October

DAY	RAIN inches	MAX T F	MIN T F	SOLAR RAD[1]	SMALL PAN EVAP[2]
1	0.18	82	71	1025	32
2	0.01	80	70	917	27
3	0.00	83	70	782	27
4	0.00	81	72	759	26
5	0.00	83	70	1077	39
6	0.22	82	72	1477	61
7	0.00	82	68	567	30
8	0.00	83	68	1099	50
9	0.00	83	72	1147	45
10	0.01	82	68	1152	40
11	0.07	82	68	976	50
12	0.05	79	68	841	65
13	0.00	82	70	970	47
14	0.00	82	68	1271	52
15	0.00	83	70	781	27
16	0.10	80	63	613	11
17	0.09	82	65	924	31
18	0.00	80	67	678	25
19	0.01	80	68	1009	35
20	7.96	82	68	558	0
21	0.14	78	72	406	20
22	0.00	82	70	1059	25
23	0.00	82	70	919	30
24	0.02	81	70	975	34
25	0.00	83	71	975	36
26	0.00	82	72	939	46
27	0.00	79	72	702	
28	0.00	78	68	610	26
29	0.00	79	68	1174	35
30	0.01	66	78	875	34
31	0.00	64	80	993	40

1 Solar Rad=Solar Radiation (langley/day x 0.468)
2 Small Pan Evap=Small Pan Evaporation (mm/day x 0.548)

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